

Longer-Term Forecasting of Commodity Flows on the Mississippi River: Application to World Grain Trade

NETs at SLC
Jan 13, 2006

Scope

- Brief Method summary
- Results from model simulations are summarized in ppt below
- Papers
 - 3 in process and available
- Outline
 - Base case, back casting and calibration
 - Projections: w/wo expanded locks
 - Sensitivities
 - Risk analysis

NAS REview

- *Model development efforts have not adopted, for example, realistic assumptions regarding spatial variation in grain production and shipping costs, the range of ports that might be accessed by regional grain production, domestic processing demands and the location of these demands, or global grain supplies and demands. The restructured study also assumes that the division of grain exports among available ports will not change, which is an unlikely assumption. As lock congestion builds on the U.S. inland waterway system, domestic markets and alternative ports and routing become increasingly feasible and likely ...Moreover, since 80 percent of U.S. corn production is domestically consumed, some dimension of this demand should be explicitly modeled. With some improvements and adjustments, existing spatial grain models could be adapted to give superior insight to the approaches currently considered by the Corps. ...Our committee has not sufficiently studied the Panama Canal transportation demand model to be able to recommend it specifically for use in the UMR-IWW study; however, it is a fully developed model that goes a long way toward incorporating the elements of a full spatial equilibrium model and it merits investigation by the Corps. (p. 15)*

Challenge!

- Shortages: in some years the supplies produced were inadequate to meet demands.
- Wheat: peculiarities of the wheat market.
- Macro model of world grain trade
 - a large scale model of world grain production and transportation to determine intercountry levels of production and trade flows, as well as the determination of production of each crop in each country and region.
- SOLVED SIMULTANEOUSLY WITH
- Micro spatial flows in the US
 - simultaneous allocation of shipments among modes and among different segments, or Reaches in the U.S. river and transportation system.
- High degree of international aggregation that was solved simultaneously with a highly micro focused U.S. domestic and export shipping (intermodal, inter-reach and inter-port) industry.
- Backcasting: Optimization models not natural for backcasting
- Projections: 50 years ouch!

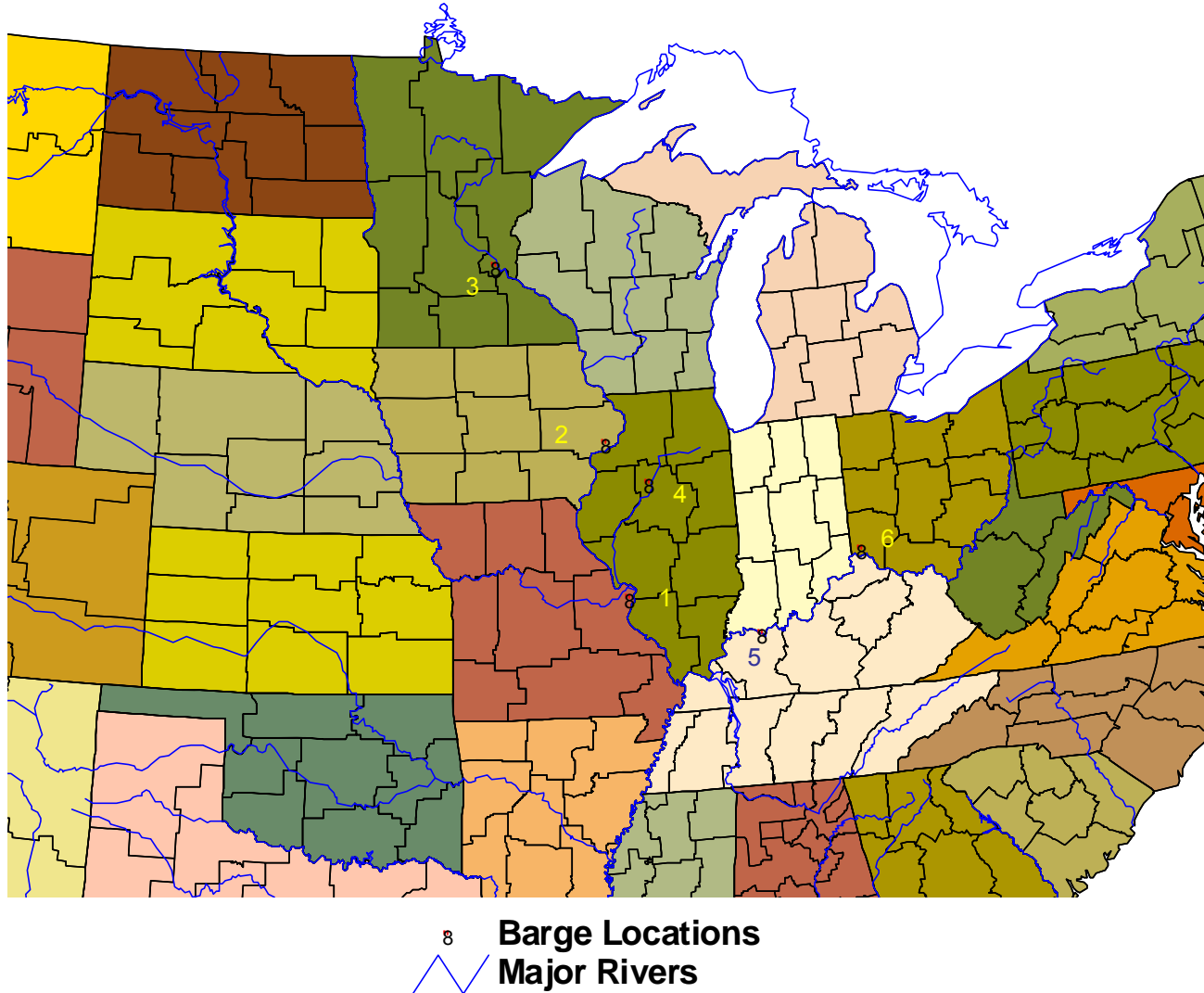
Model Specification: Overview

- Model is nonlinear (due to delay costs) where
- Objective
 - Minimize costs
 - Costs include:
 - production,
 - interior shipping,
 - handling,
 - ocean shipping costs
 - production and export subsidies and import tariffs
 - Subject to
 - Meeting demands
 - Area planted restrictions in each region (total arable land is restricted)
 - Rail, barge transfer at StLouis and USGulf
 - Barge capacity (as delay functions)
- Selected other restrictions (see Table 10.1 p. 104)
 - Wheat

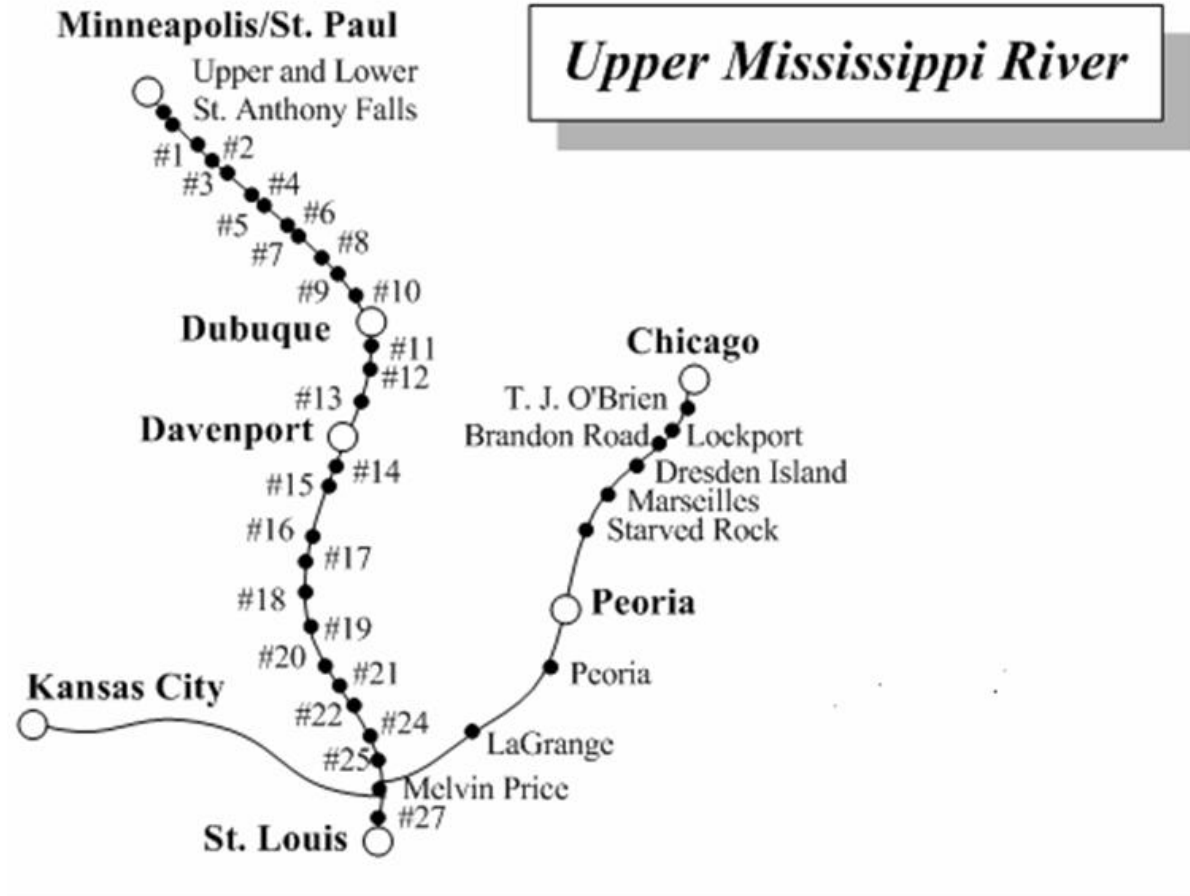
Reach Definitions

- Reach 1 Cairo to LaGrange (St Louis)
- Reach 2 LaGrange to McGregor (Davenport)
- Reach 3 McGregor to Minneapolis (Minneapolis)
- Reach 4 Illinois waterway (Peoria)
- Reach 5 Ohio River Cairo to Louisville (Louisville)
- Reach 6 Ohio River Cincinnati (Cincinnati)

Reach Center-Point Definitions

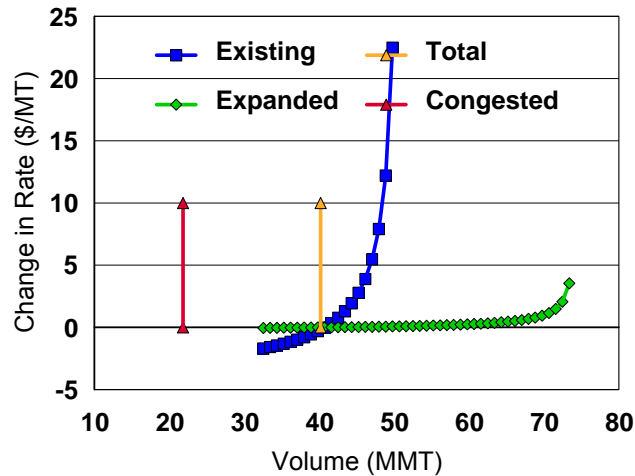


Map of Reaches

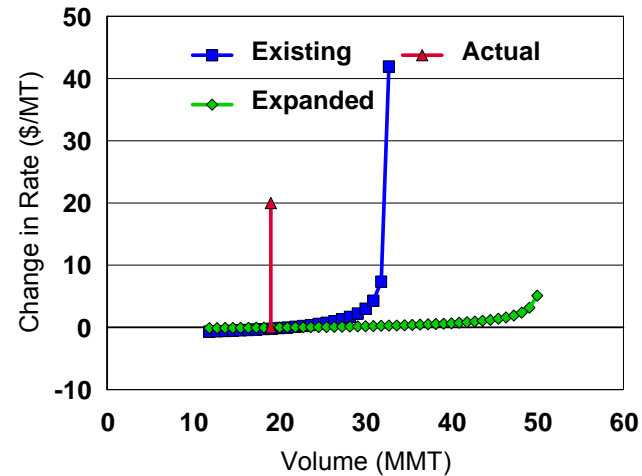


Relationship Between Change in Barge Rate and Volume by Reach and Existing vs. Expanded Capacity

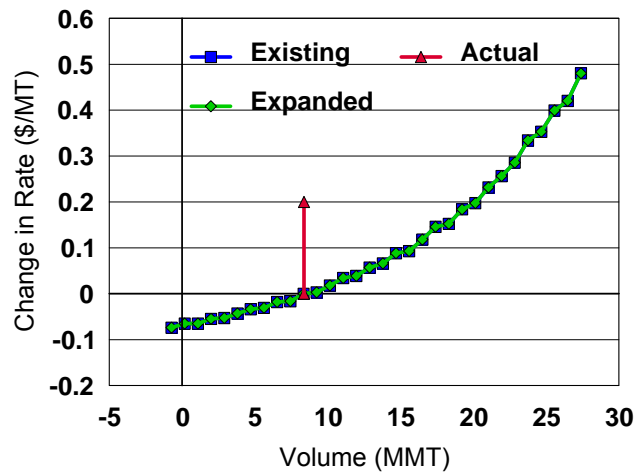
Reach 1



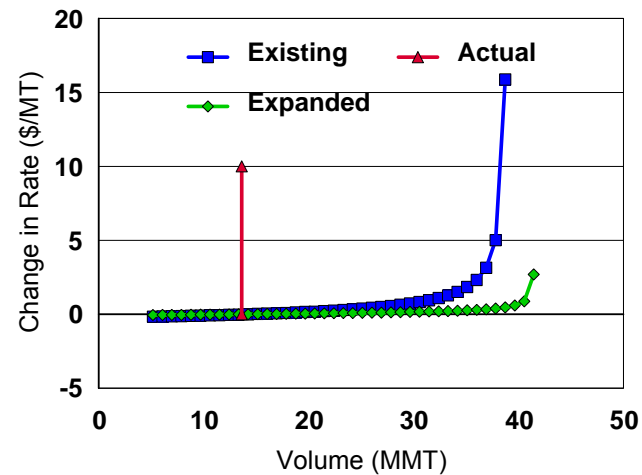
Reach 2



Reach 3

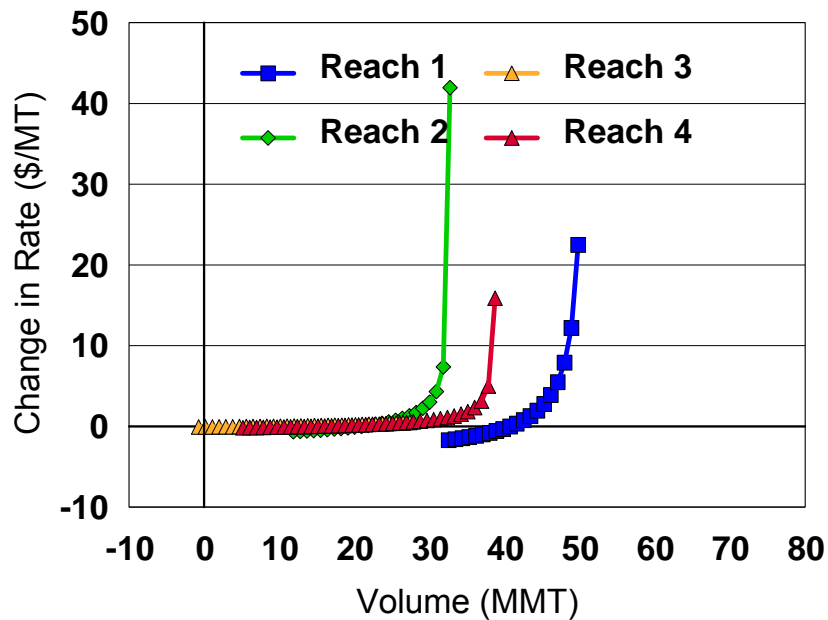


Reach 4

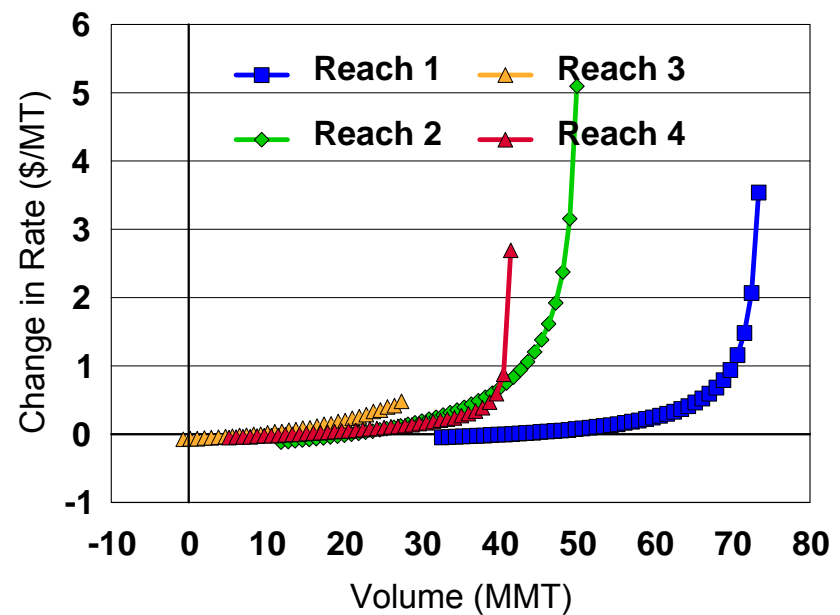


Relationship Between Change in Barge Rate and Volume by Reach and Existing vs. Expanded Capacity

Reach 1-4 Existing



Reach 1-4 Expanded



Objective Function

$$\begin{aligned} W = & \sum_c \sum_i (PC_{ci} - S_i) A_{ci} + \sum_c \sum_i \sum_j t_{cij} Q_{cij} \\ & + \sum_c \sum_i \sum_p t_{cip} Q_{cip} + \sum_c \sum_p \sum_q (t_{cpq} + r_q) Q_{cpq} \\ & + \sum_c \sum_w \sum_p \left(t_{cwp} + B_p \right) Q_{cwp}^w \end{aligned}$$

where

i=index for producing regions in exporting countries,

j=index for consuming regions in both exporting and importing countries,

p=index for ports in exporting countries,

q=index for ports in importing countries,

PC_{ci}=production cost of crop c in producing region i,

A_{ci}=area used to produce crop c in producing region i,

t=transportation cost per ton,

Q=quantity of grains and oilseed shipped,

S=production subsidies in the exporting country;

r=import tariffs in the importing country;

B=delay costs associated with barge shipments on each of four reaches on the Mississippi river.

Restrictions

- 1)
$$Y_{ci} A_{ci} \geq \sum_j Q_{cij} + \sum_p Q_{cip}$$
- 2)
$$\sum_c A_{ci} \leq TA_i$$
- 3)
$$A_{ci} \geq MA_{ci}$$
- 4)
$$\sum_i Q_{cij} + \sum_q Q_{cqi} \geq MD_{cj}$$
- 5)
$$\sum_c \sum_i Q_{cip} \leq PC_p$$
- 6)
$$\sum_c \sum_i Q_{ciw} \leq LD_w$$
- 7)
$$\sum_i Q^R_{cip} + \sum_w Q^R_{cwp} \geq MQ_{cp}$$
- 8)
$$\sum_i Q_{cip} = \sum_q Q_{cpq}$$
- 9)
$$\sum_p Q_{cpq} = \sum_j Q_{cqi}$$

where

y =yield per hectare in producing regions in exporting countries,
 TA =total arable land in each producing regions in exporting countries,
 MA =minimum land used for each crop in producing regions in exporting countries,
 MD =forecasted domestic demand in consuming regions in exporting countries and import demand in consuming regions in importing countries,
 PC =handling capacity in each port in both exporting and importing countries,
 LD_w throughput capacity for grains and oilseeds at river access point W ,
 MQ_p in the minimum quantity of each crop shipped through each port in the U.S.

Model and relation to routing

- Model is comprehensive including
 - Int'l production and shipping
 - Domestic production and shipping
 - Shipments interior by
 - Mode (rail, truck, rail/barge, truck/barge)
 - Route—interport
 - Route—inter-reach (6 reaches) competition
- Elements could be broken out to be integrated into or component of larger more detailed routing effort.

Rail Cost Differentials: Corn

Table 6.6.6 Corn Cost Differential: Illinois North to Reach 4 vs Reach 1

	Weighted Average Rates (mt)			Cost Differential to US Gulf
	Reach 1	Reach 4	Differential	4 vs 1
1995	6.35	5.14	1.21	4.23
1996	11.58	7.16	4.42	1.02
1997	8.00	4.28	3.72	1.72
1998	5.68	4.34	1.34	4.10
1999	6.25	4.78	1.47	3.97
2000	3.33	4.86	-1.53	6.97
2001	3.19	3.82	-0.63	6.07
2002	3.98	5.75	-1.76	7.20

Corn to PNW

Table 6.6.3. PNW: Weighted Average Rail Shipping Rates (\$/MT) for Selected Production Regions to PNW, by Crop, 1995-2002.

[illegible]

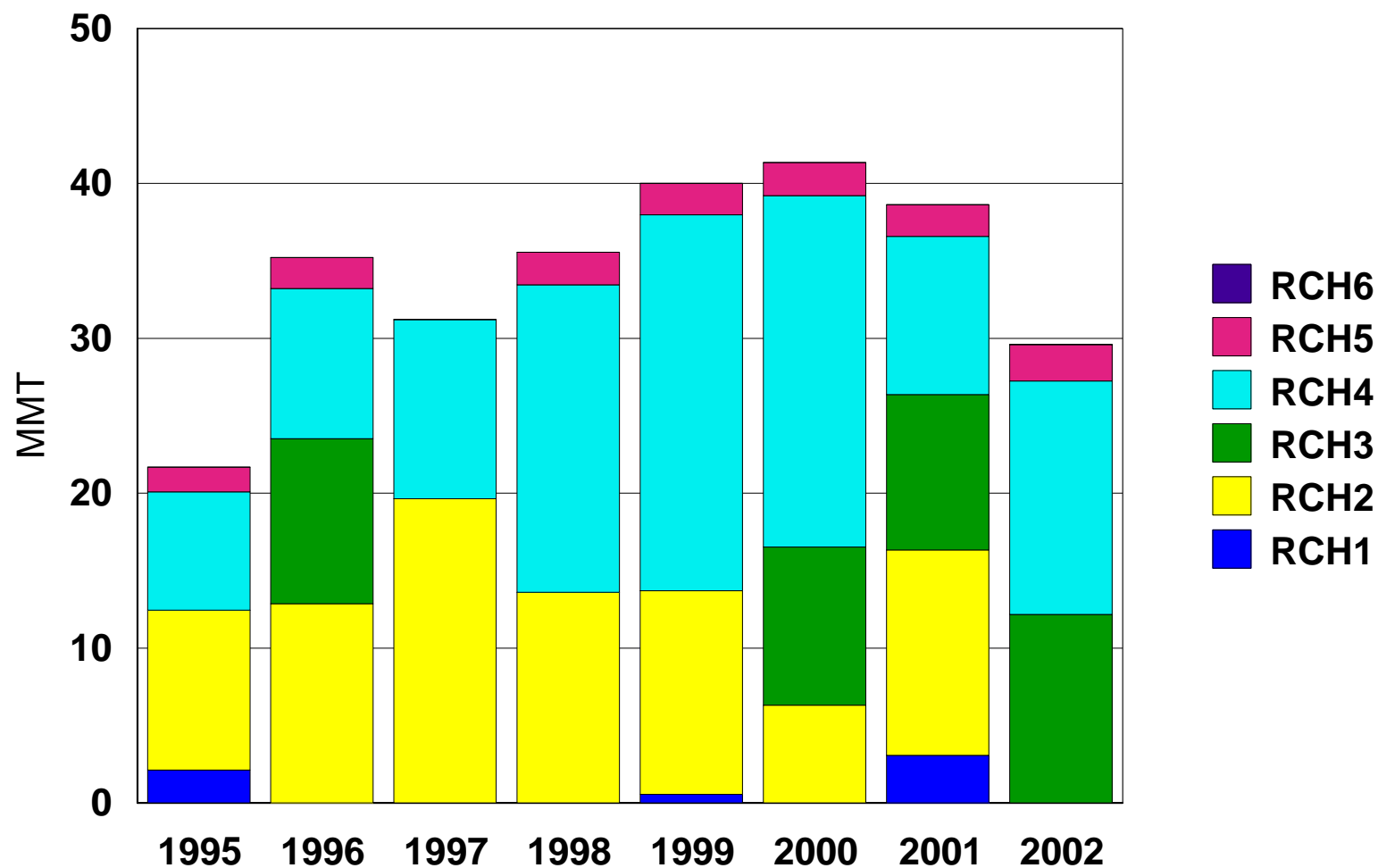
StLouis/US Gulf Transfer Restriction

- Restrictions:
 - Imposed on rail transfer; else
 - large scale rail shipments and transshipments—larger than observed
- St Louis study
 - Peak year 1997
 - Since then, Brazil/Argentina, increased local use, PNW, Shuttles and ethanol
- Capacity appears to be suggested about
 - 7.6 mmt 2005 throughput
 - 13 mmt based on 1997 throughput
 - 15 mmt if spread over entire year
- Rationalize
 - Waybill rates likely don't adequately account for shuttles
 - Underestimate shipper obligation for load/unload and cycle
 - Don't account for preference to shippers for truck or barge which are less restrictive on shuttle-type obligations

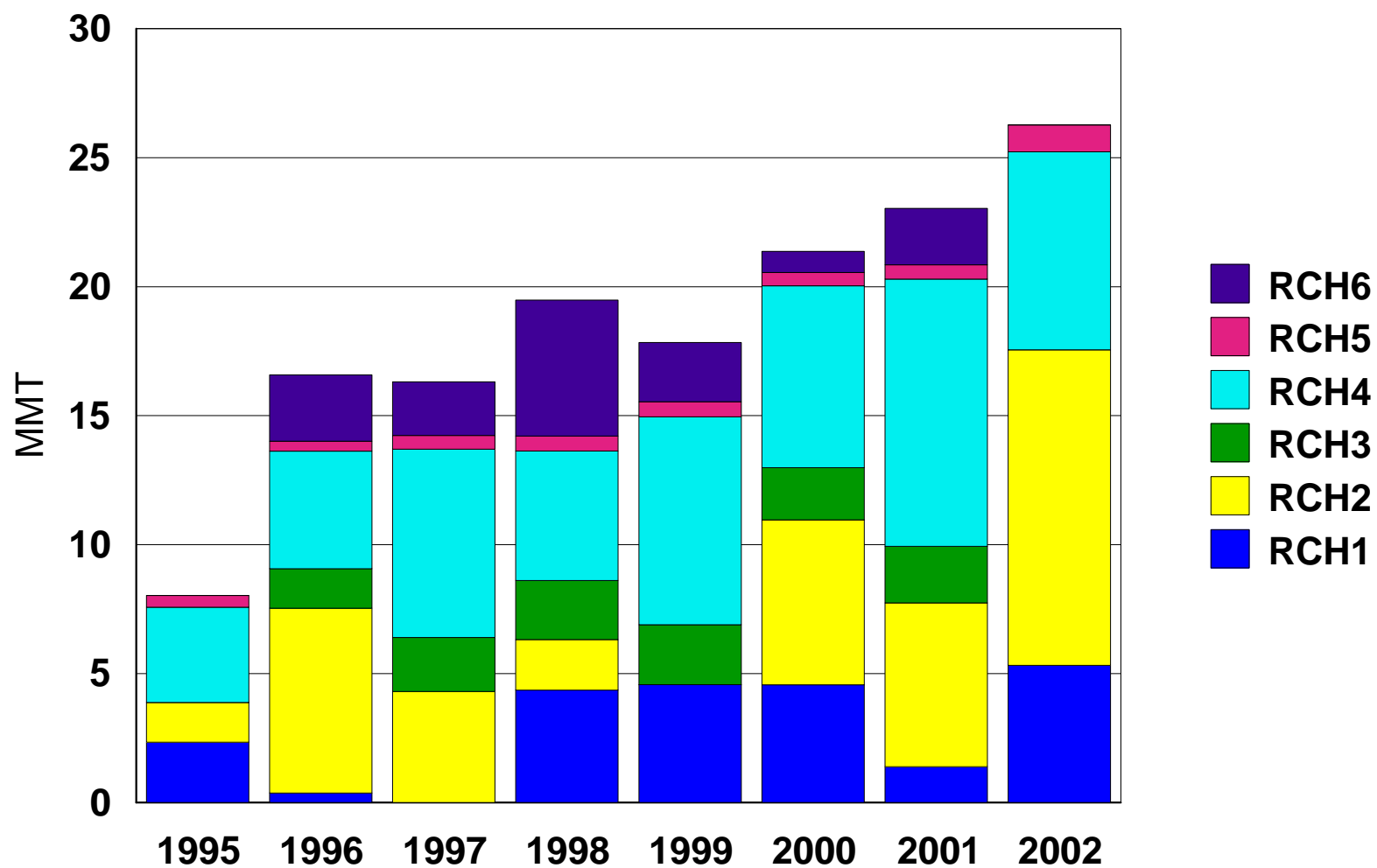
Base Case, calibration and back casting

- Backcasting:
 - Short-run observations vs. longer term adjustments!
 - Model reflects longer-term adjustments in trade flows, modal shipments and cropping patterns
 - Shorter-term, adjustments, particularly in cropping patterns, are not as apparent.
 - Calibrate for particular year, then impose on other years precludes capturing peculiarities of individual years
- Results
 - Generally reflective of general trends
 - Chart below show projections by reach; and to follow show actual flows by reach

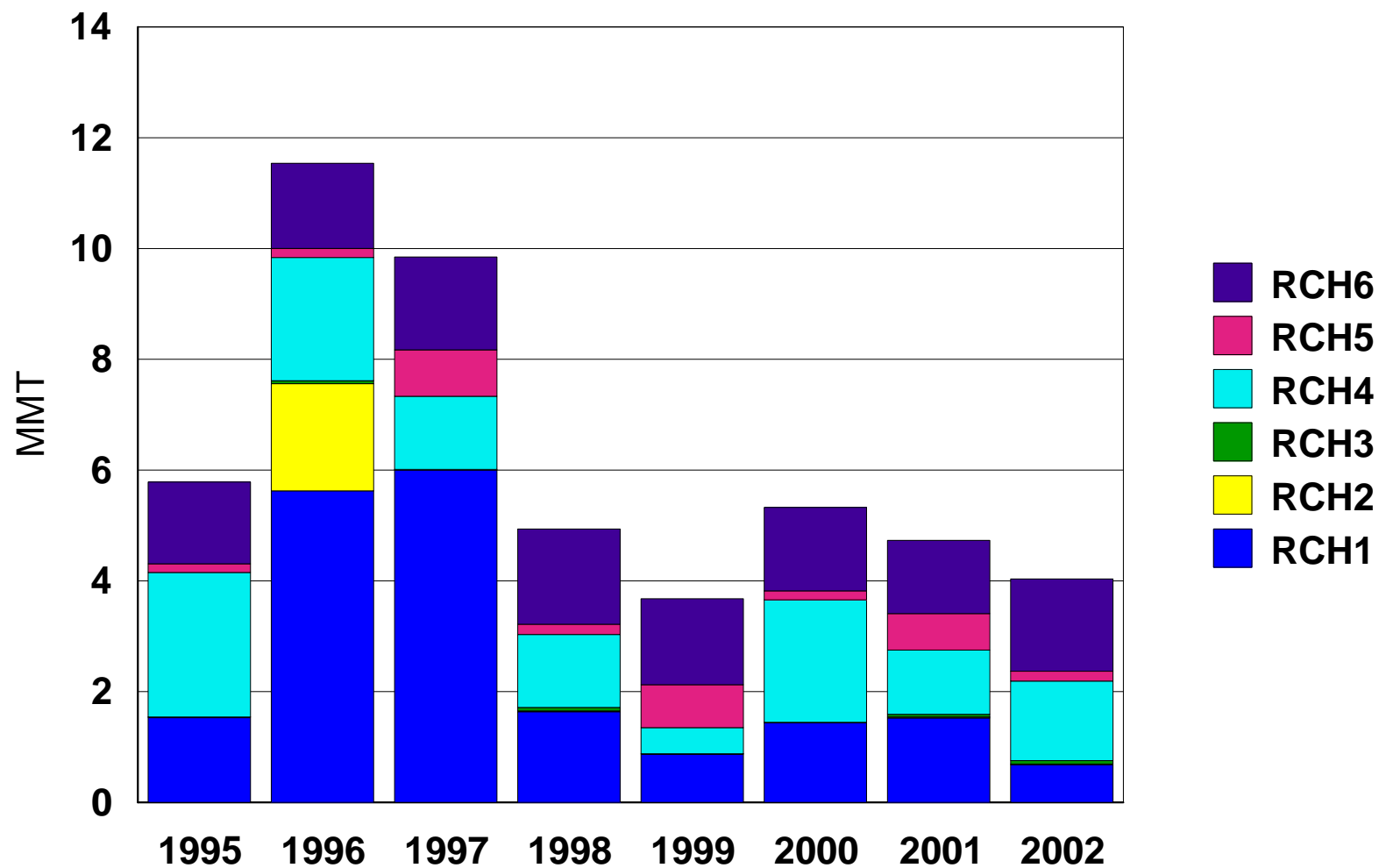
Reach Shipments: Corn



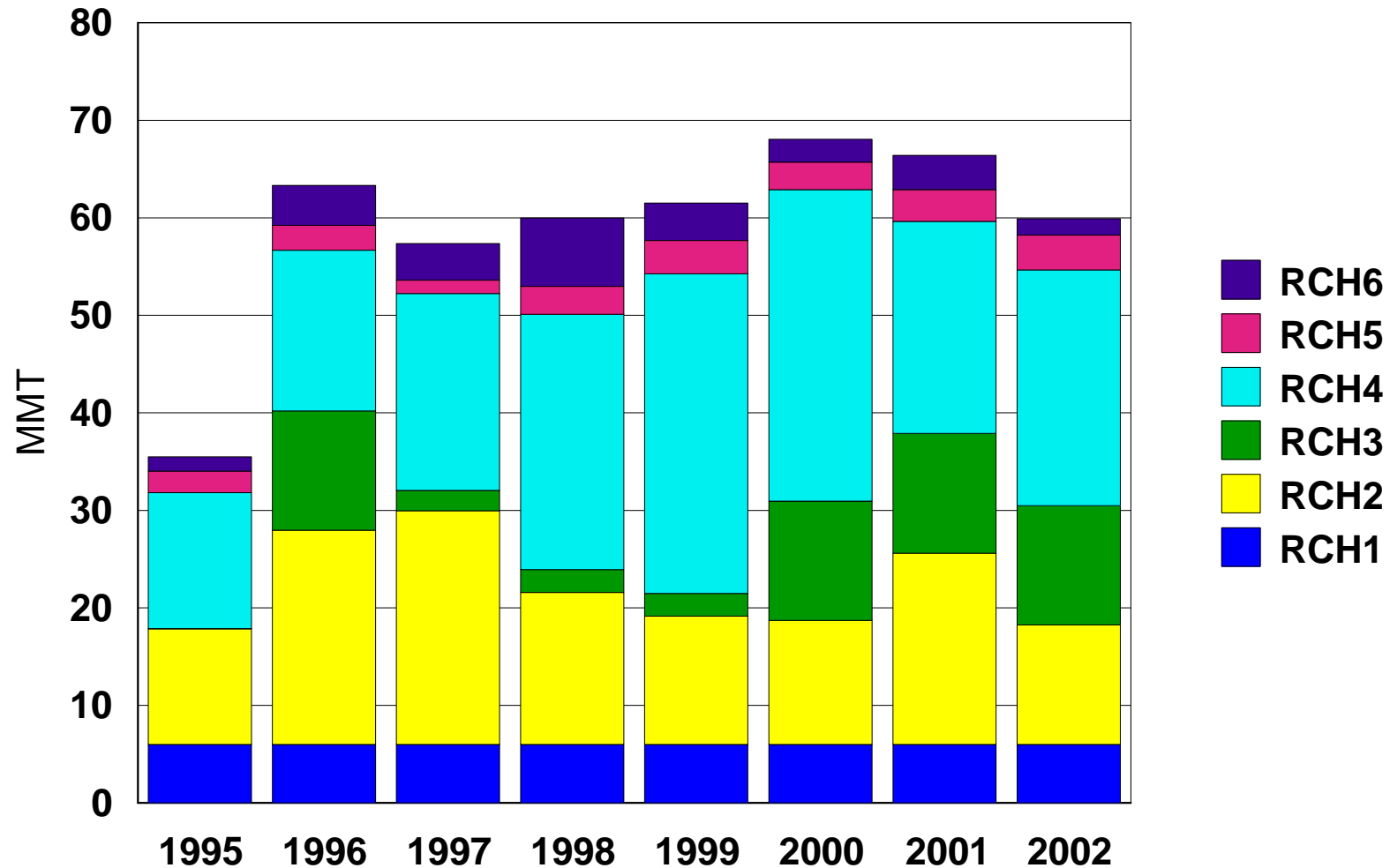
Reach Shipments: Soybeans



Reach Shipments: Wheat



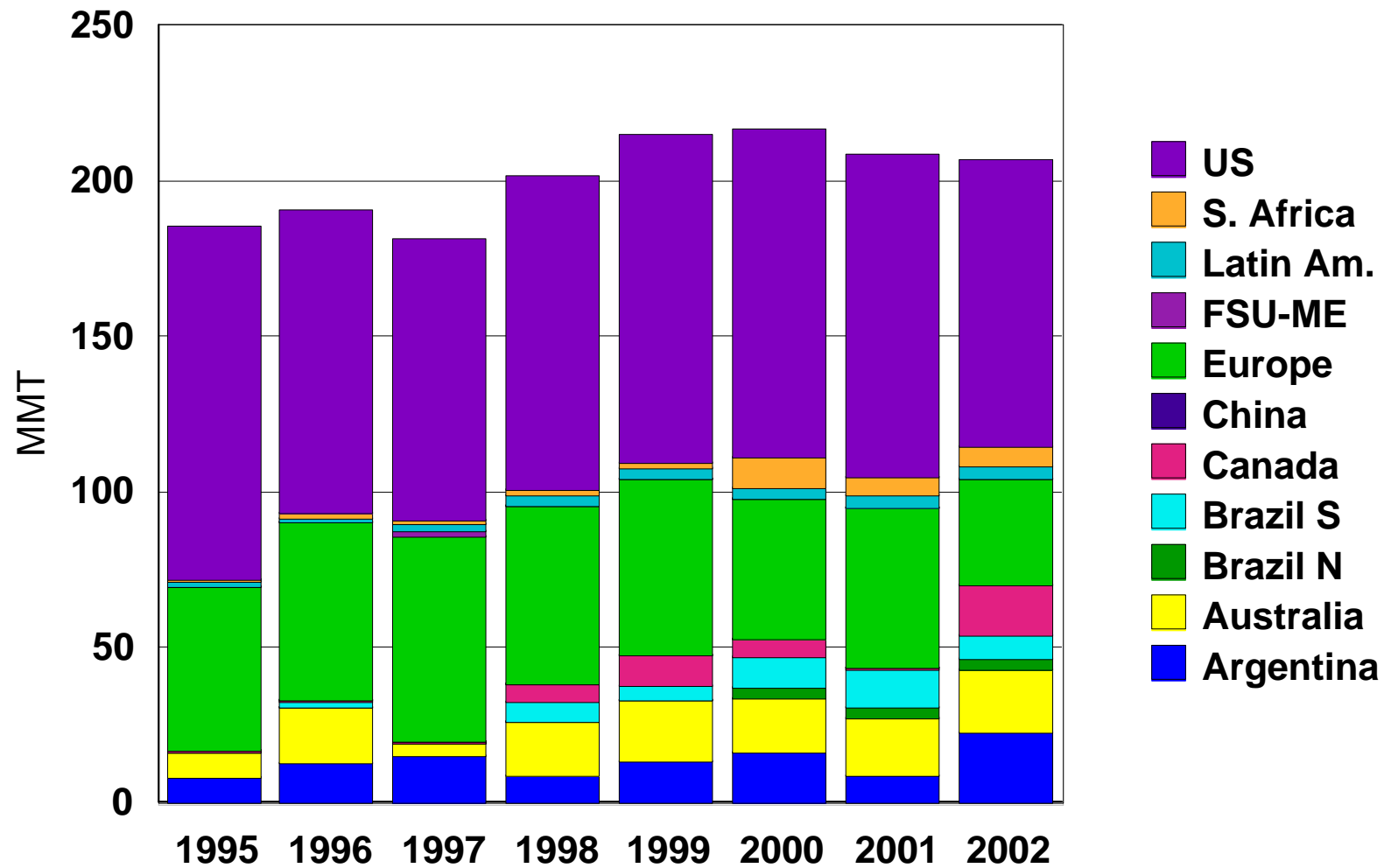
Reach Shipments: Corn, Soybeans and Wheat



Summary

- Results are somewhat robust with respect to total movements
 - Corn: Model reflects actual barge loadings but slightly overstate actual movements
 - Wheat: Model overestimates barge loadings
 - Soybeans: Model overestimates barge loadings

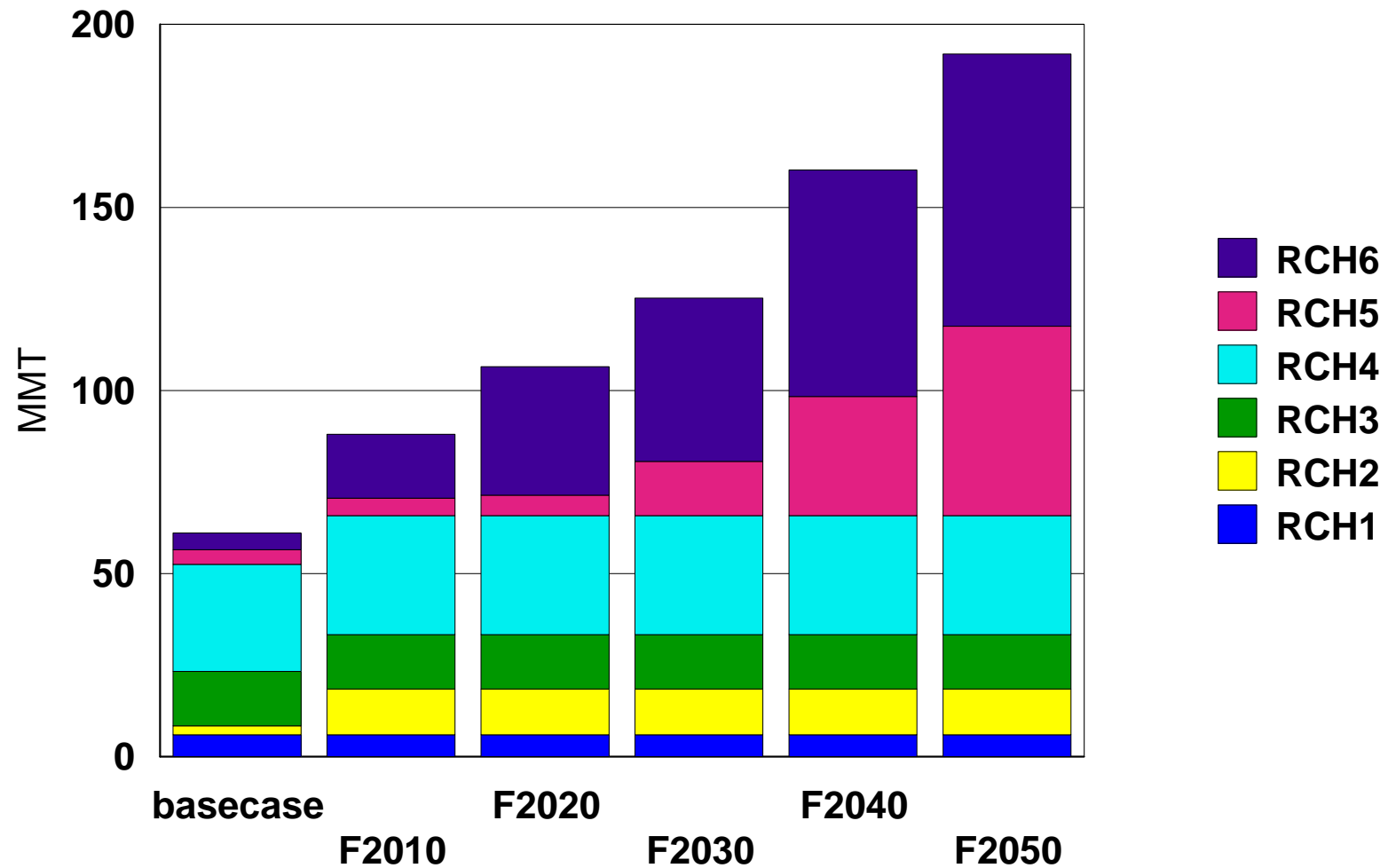
Total Exports by Country



Projections: Existing Capacity

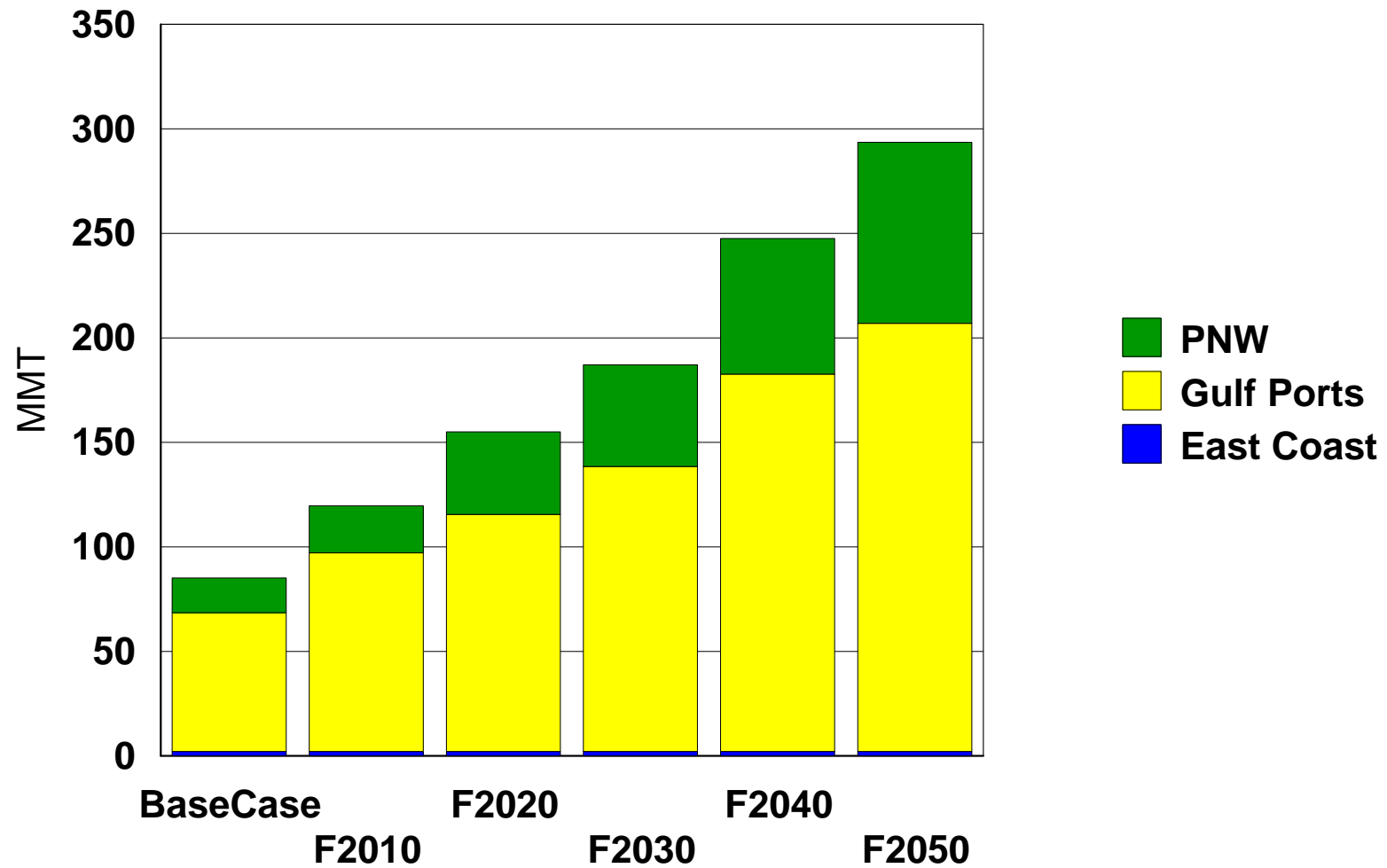
- Assumptions
 - WEFA growth in income and population.
 - No subsidies beginning in 2010
- Model run
 - With existing capacity and delay costs
 - With expansion in barge capacity and corresponding delay costs
 - Revised to examine impacts in 2010 of EU corn

Reach Shipments: Forecast Existing Capacity



Forecast Export Volume by Port

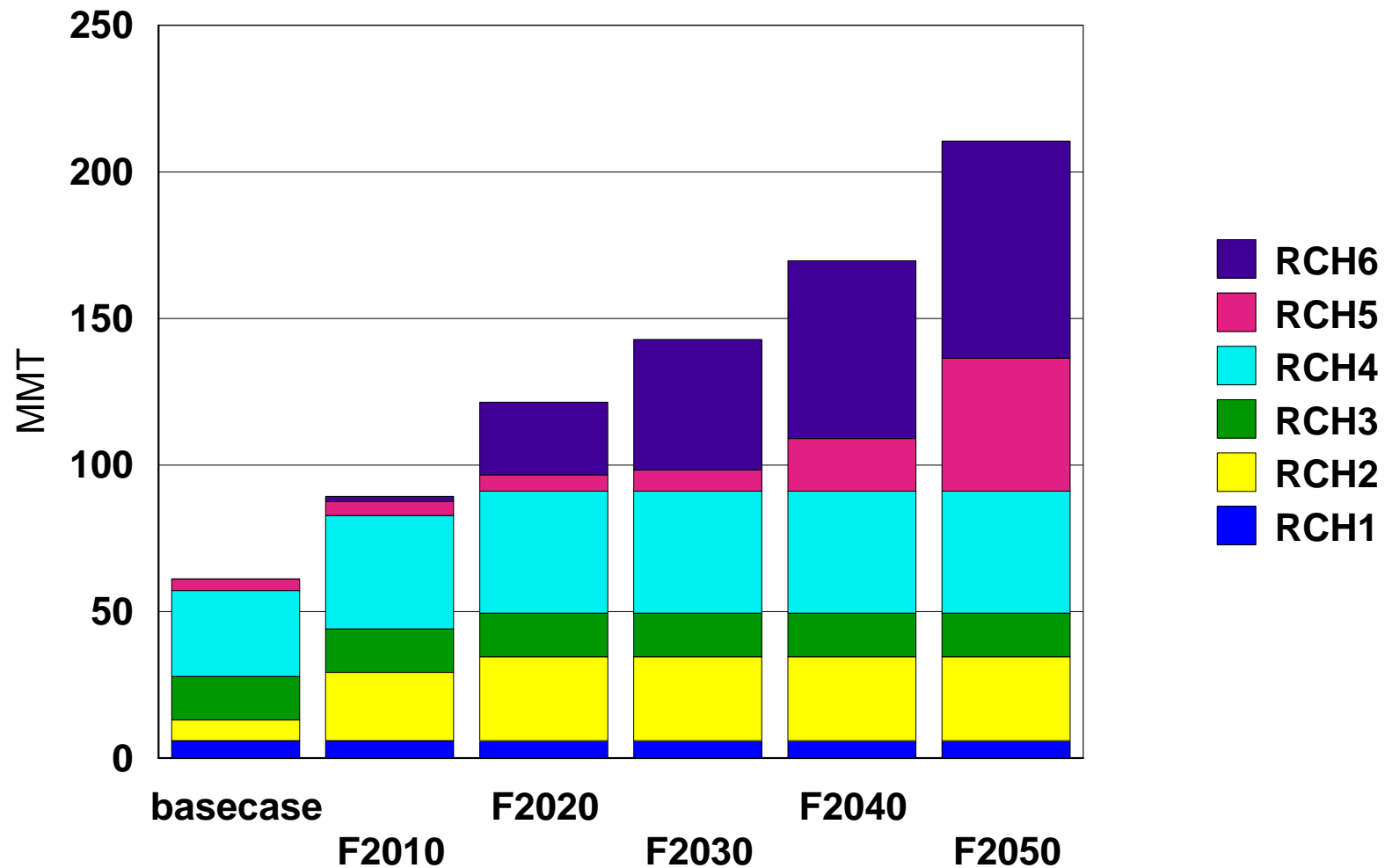
Existing Capacity



Expanded Capacity Forecasts

- Delay Functions modified to reflect expanded capacity modifications
- Results shown are
 - Actual levels
 - Changes in Reach flows associated with the expanded locks

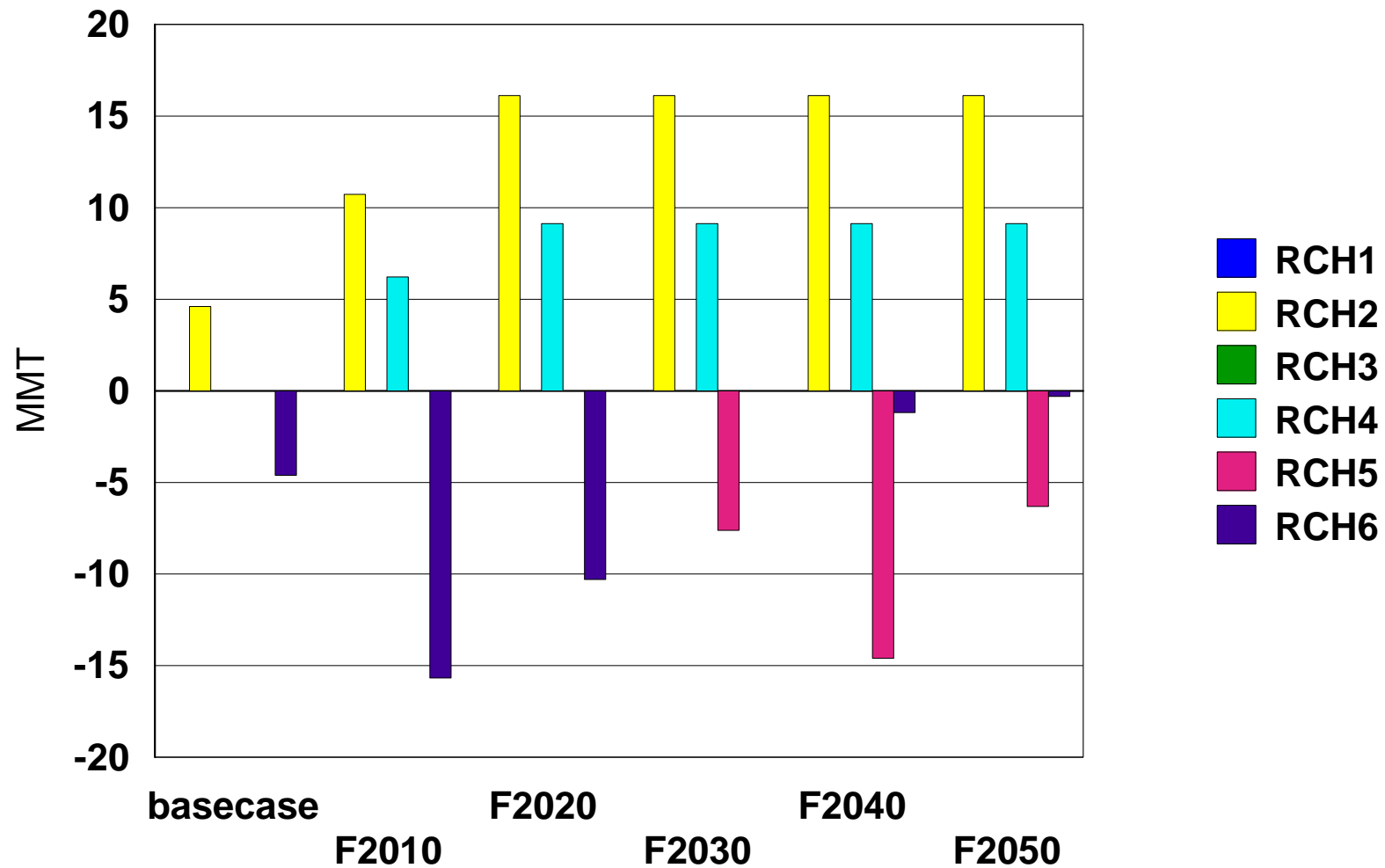
Total Reach Shipments: Expanded Capacity Forecast



Comment

- In period through 2040,
 - US yields increase faster than those in FSU/ME
 - As result, costs in FSU/ME increase on per mt basis
- By 2040, there is a shift from these countries to the US, resulting in increased barge flows

Change in Total Reach Shipments: Expanded Capacity Forecast



Comment

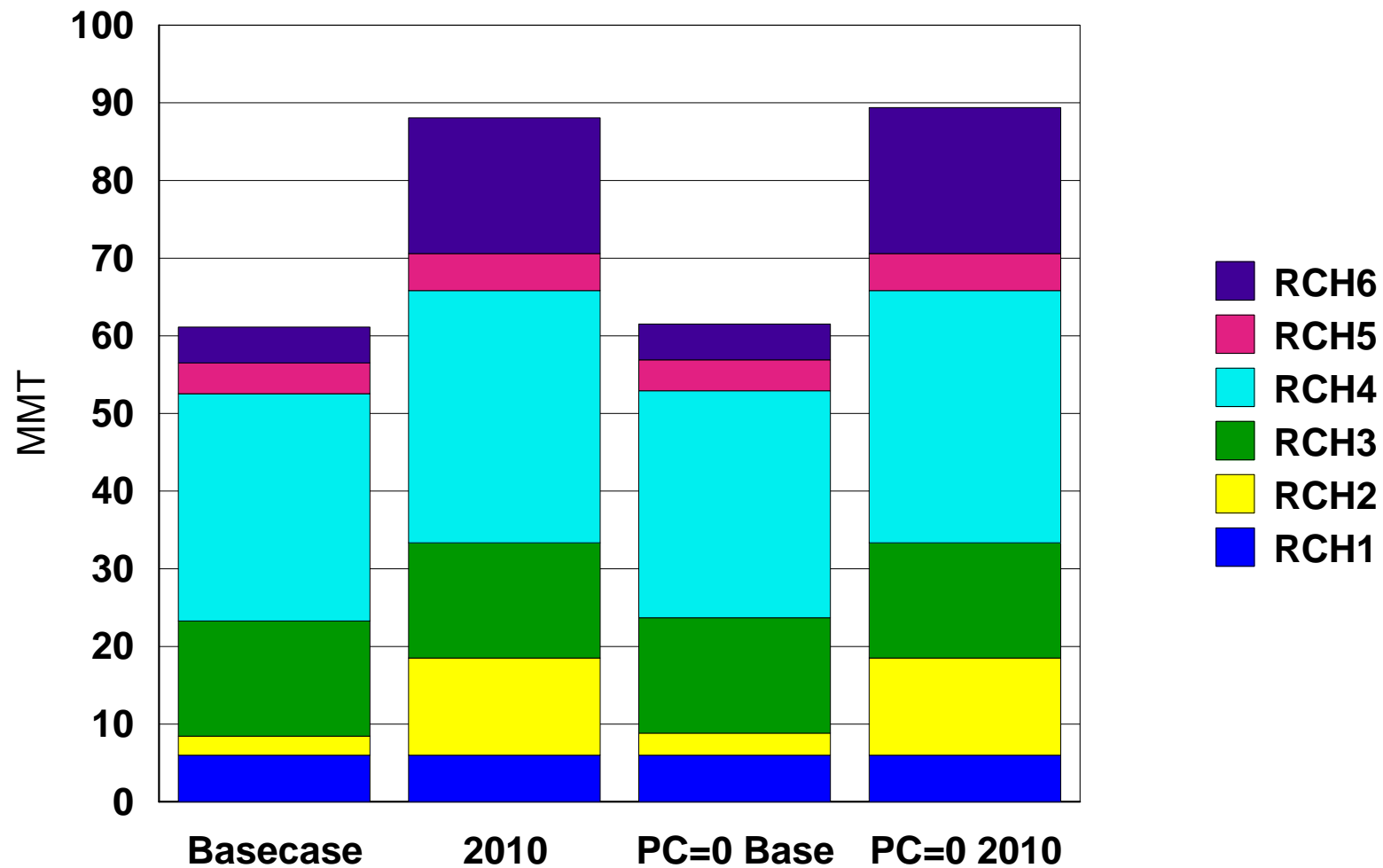
- Eliminating the delay costs all reaches has the effect of shifting flows
 - Increasing flows through/from Reach 2 and 4
 - Reducing flows from Reaches 5 and/or 6

Projections 2

- To examine impacts of production costs on the model results
- Model re-run assuming zero production costs in Base Case and 2010

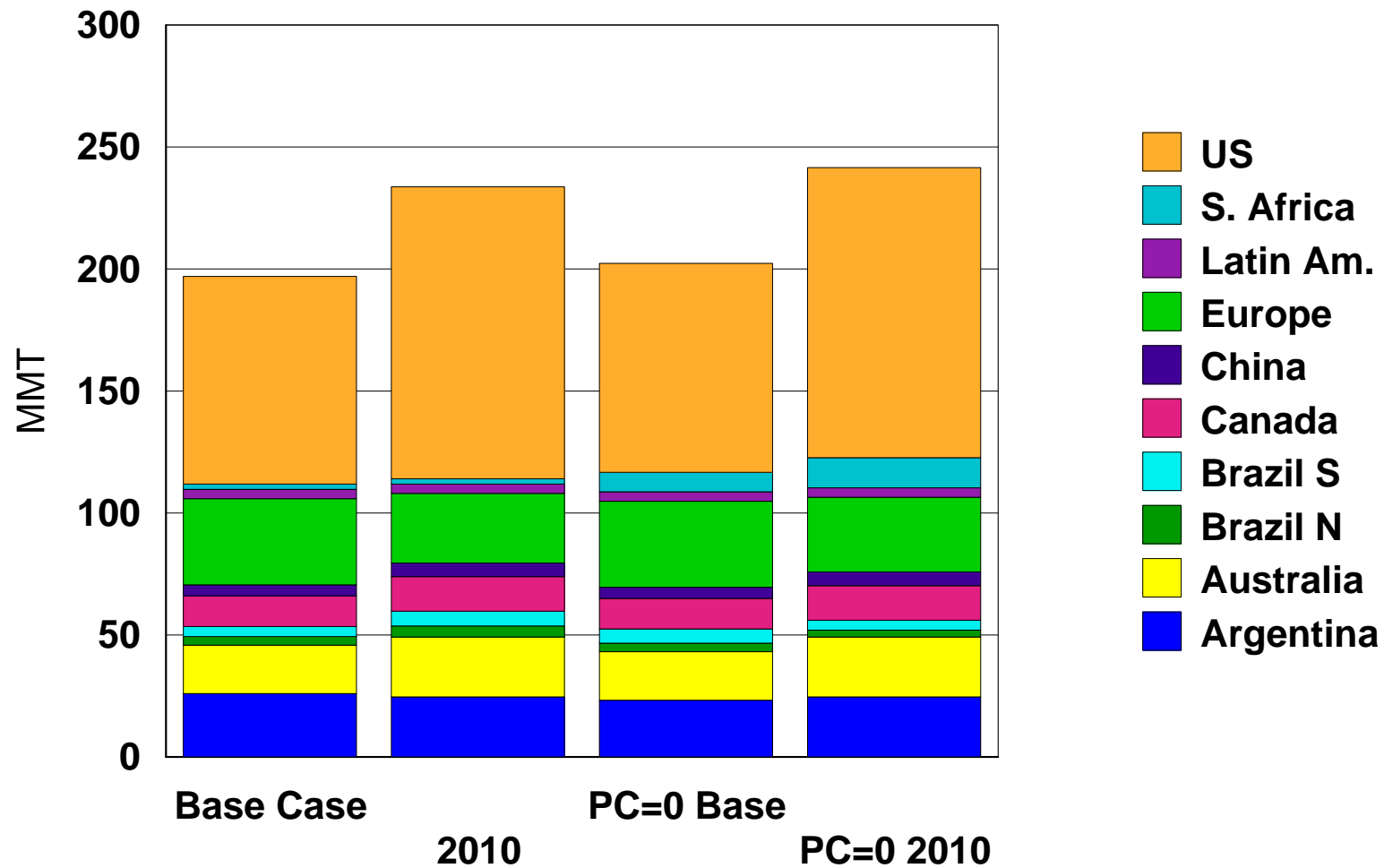
Reach Shipments

With and Without Production Costs



Export Shipments

With and Without Production Costs



Summary

- Impacts of production cost variability across countries has limited impact on total exports
- US land area
 - Limited
 - in many cases land planted is decreasing
- Competing countries land area
 - expanding
- Trending yields have differential impacts on prod costs
 - US losing advantage in wheat costs
- Increased domestic consumption reduces exportable supplies

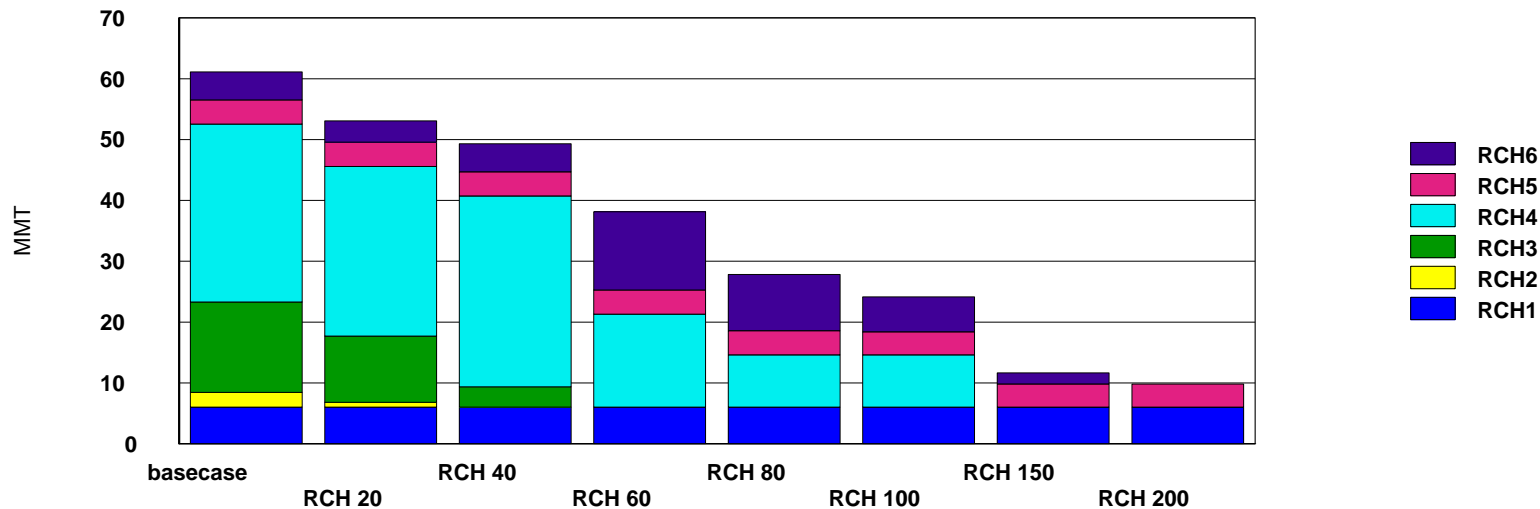
Projections 3

- In 2010 there is an increase in exports
 - Virtually all of this is corn
 - Results from a subtle shift in EU production costs
 - EU production costs increase relative to US costs
 - Reduced production and exports of corn from EU
 - Expansion of exports from US

Sensitivities

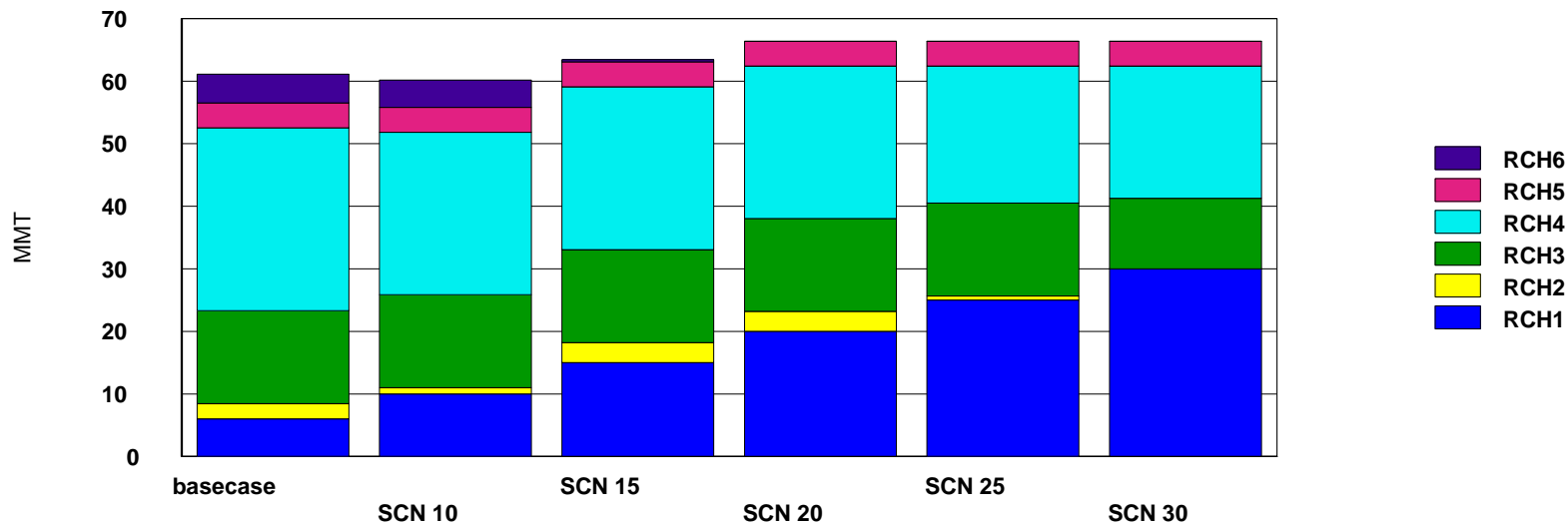
- Assumptions
 - 2002 model base model
- Barge and Logistical Restrictions
 - Barge demand analysis (long-run)
 - New Orleans
 - Reach 1
 - Expanded system
- PNW Spreads
- Panama—decrease shipping costs by \$2/mt
- Free Trade
 - No subsidies (prod or export) in 2010
- Other macro trade
 - Increased ethanol
 - Brazil
 - China demand

Sensitivities Barge Rates: Long-run Demand Curve



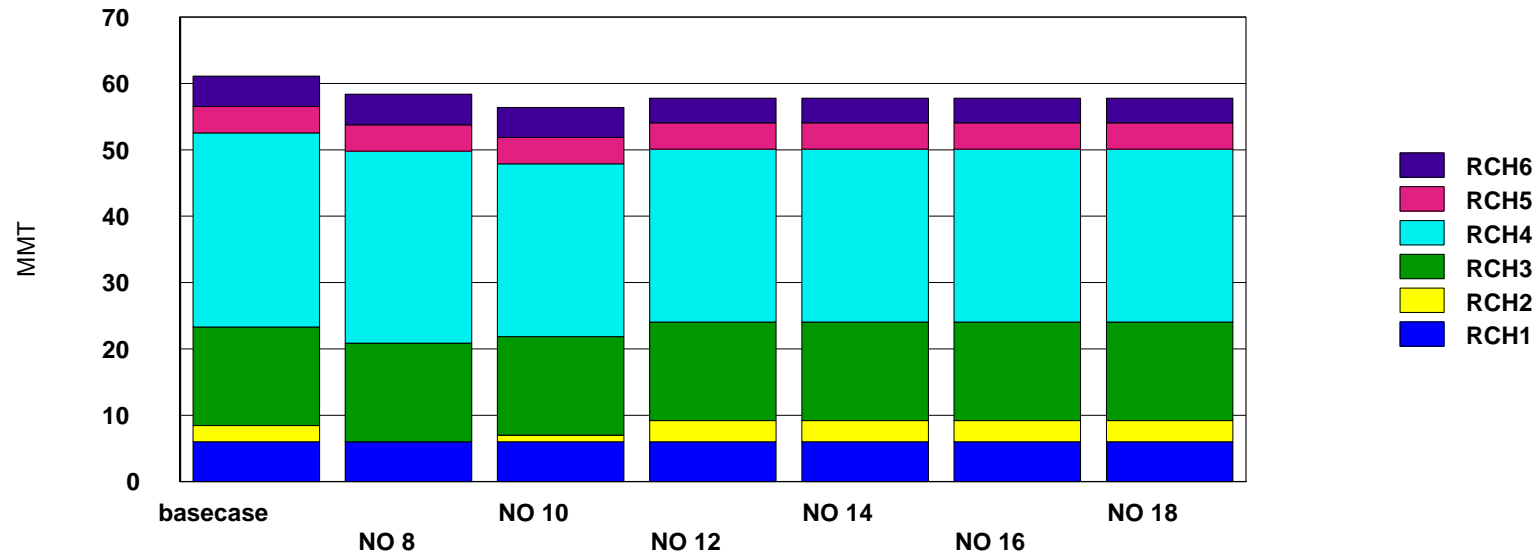
- Barge rates increased by 20 to 200%
- Results
 - Decline in barge shipments
 - Most of decline first in Reach 3; then Reach 4
- Interpretation:
 - This is the longer-term demand for barge shipments;
 - Allows for the simultaneous adjustments in trade flows, modal shipments and cropping patterns
 - Implies a longer-run demand elasticity of about -.8 for 20% increase in barge rates

Sensitivities: Reach 1 Capacity



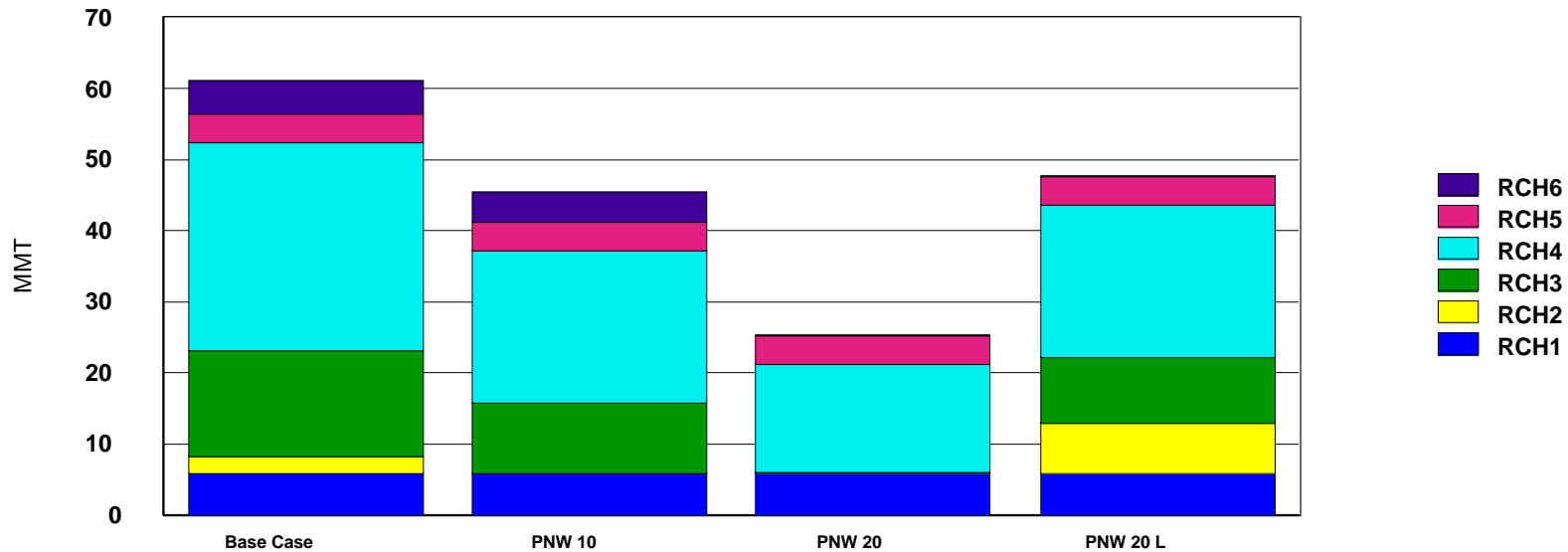
- Base case restriction on Reach 1
 - Restricted to allow a maximum of 6 mmt transferred from truck/rail to barge (reflective of max of recent years observations)
- Relax restriction and allow 10, 15..up to 30 mmt
- Result
 - Total barge shipments increase slightly
 - Biggest change is shift from Reach 4 to Reach 1
 - This reflects that a large volume would ship from Reach 4 to Reach 1 if this transfer restriction were relaxed

Sensitivities: New Orleans Rail Capacity



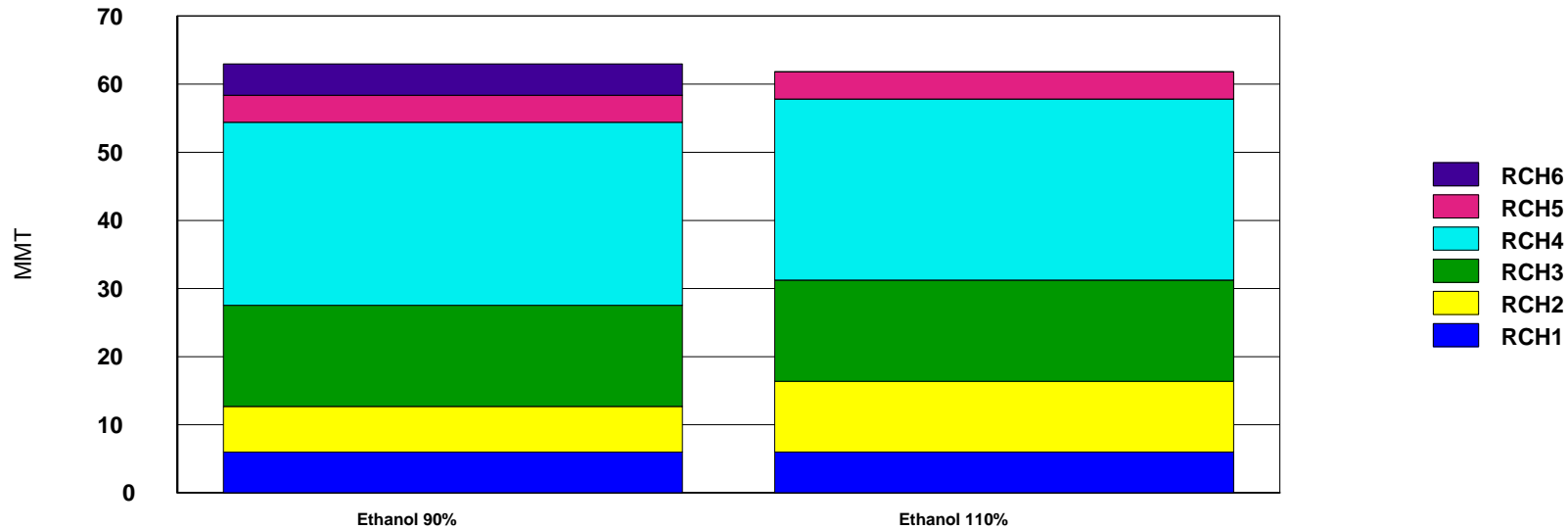
- Base case restriction on New Orleans rail transfer
 - Restricted to allow a maximum of 6 mmt transferred from rail to exports at New Orleans (reflective of max of recent years observations)
- Relax restriction and allow 8, 10, 12..up to 18 mmt
- Result
 - Total barge shipments decrease slightly; but after about 10 mmt, barge shipments stabilize
 - Biggest change is shift from Reach 2 and 4
 - This reflects that some of these shipments would ship by rail and by-pass barge system if this transfer restriction were relaxed

Sensitivities: PNW



- Base case allowed unrestricted shipments through PNW and US Gulf/PNW ocean differential to Japan (as Asia)=\$5/mt
- Re-ran model to allow for increased ocean rate differential. Results
 - Increases in ocean rate differential to 10, and 20\$/mt results in drastic reductions in barge shipments
 - Assumes no change in barge rates
 - Barge shipments decline and are shifted to PNW
- Restricted PNW export capacity=30 mmt (approximately current capacity and utilization)
 - See PNW20L
 - This forces more shipments through US Gulf; an increase from about 24 mmt to 48 mmt at a \$20/mt ocean rate differential

Sensitivities: Ethanol Demand

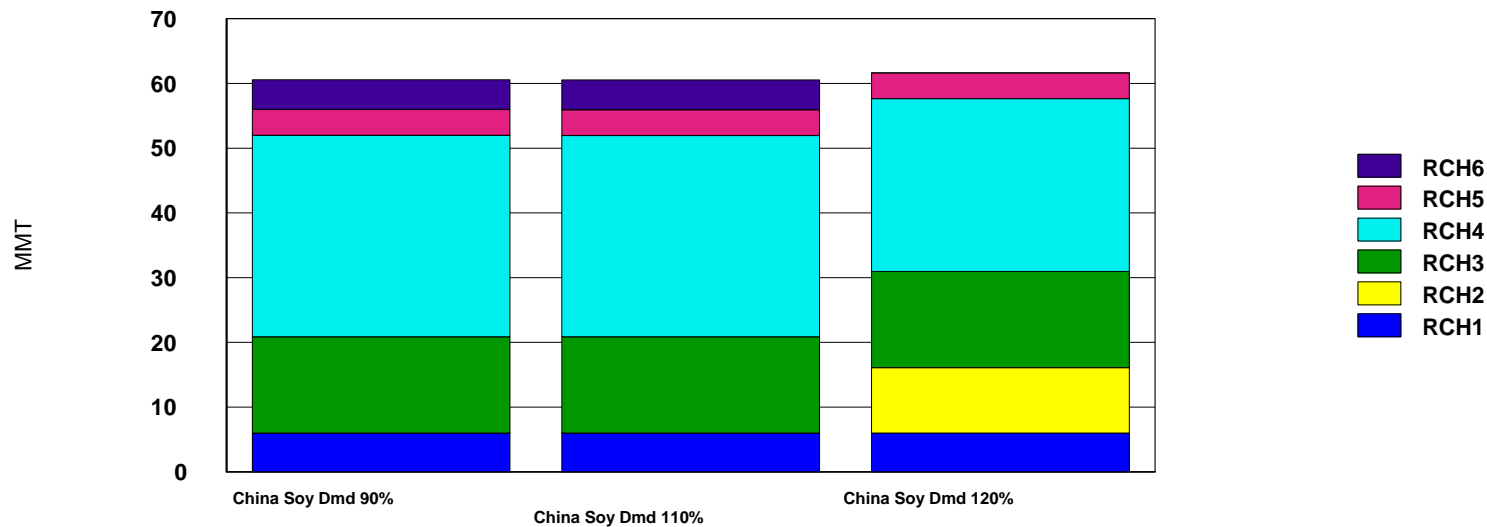


- Base case allowed current projections for ethanol demand for corn in US
- Revised to allow 10% more demand for ethanol, versus the base case
- Results
 - Slight reduction in barge demand
 - Increase in demand from Reach 2, and reduced demand from other Reaches
 - Reflects changes in cropping patterns (increased corn, reduced soybeans) in most regions

Ethanol Capacity

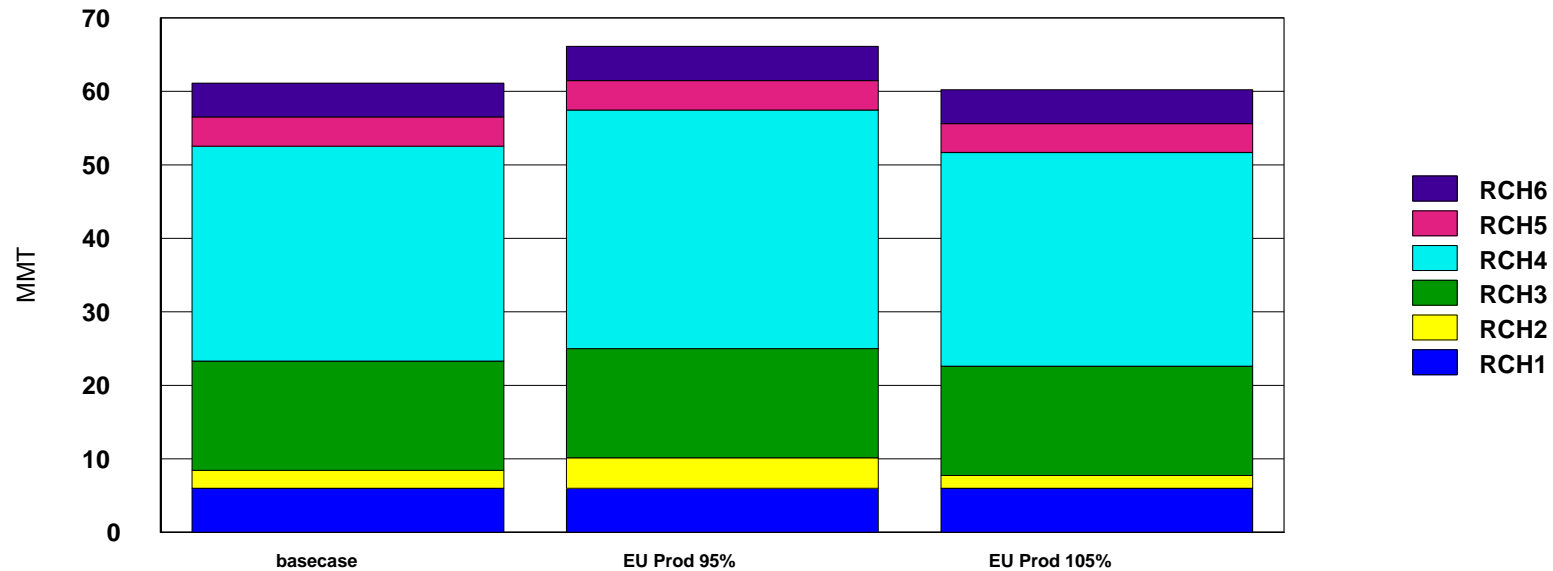
State	Existing Capacity 02/2004 mmg/year	Existing Capacity + Planned Expansion 01/2006 mmg/year	Increase	Percent of total Increase
Iowa	636.5	1176.5	540.0	0.18
Illinois	726.0	1443.0	717.0	0.24
Nebraska	425.0	868.5	443.5	0.15
South Dakota	377.0	713.0	336.0	0.11
Minnesota	398.1	553.6	155.5	0.05
Wisconsin	91.0	228.0	137.0	0.05
Kansas	109.5	206.5	97.0	0.03
Missouri	60.0	155.0	95.0	0.03
Indiana	95.0	182.0	87.0	0.03
Tennessee	65.0	67.0	2.0	0.00
Michigan	45.0	207.0	162.0	0.05
North Dakota	33.5	60.5	27.0	0.01
Kentucky	4.0	38.4	34.4	0.01
New Mexico	15.0	30.0	15.0	0.01
California	9.0	30.0	21.0	0.01
Wyoming	5.0	5.0	0.0	0.00
Idaho	4.0	0.0	-4.0	-0.00
Colorado	1.5	85.0	83.5	0.03
Washington	0.7	0.0	-0.7	-0.00
Texas	0.0	30.0	30.0	0.01
Ohio	0.0	3.0	3.0	0.00
Georgia	0.0	0.4	0.4	0.00
Total	3100.8	6082.4	2981.6	

Sensitivities: China Soybean Demand



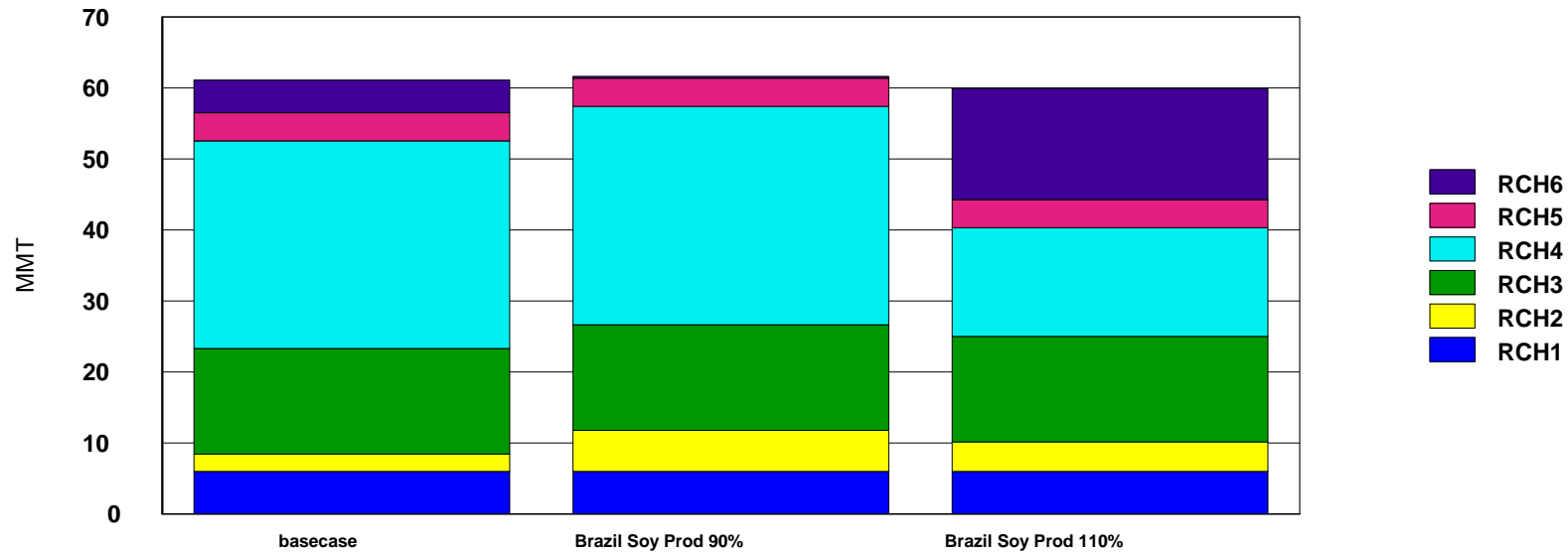
- Base case assumes normal growth in China demand for soybeans
- Model relaxed to allow changes in demand, prospectively reflecting a faster growth rate
- Results
 - Slight increase in barge flows
 - Mostly due to China demand coming from US PNW
 - Increased shipments from Reach 2, and reductions from Reach 4

Sensitivities: EU Production



- Base case uses EU production at current values
- Revised to allow reduced/expanded production in the EU
- Results
 - Reduced production in EU, results in increase in barge shipments; and vice versa
 - Increase is from each of Reaches 2-6

Sensitivities: Brazil Soybean Production



- Base case assumes current production in Brazil
- Brazil threatening to expand production
- Model revised to allow reduced and increased soybean production in Brazil
- Results
 - Reduced Brazil production increases barge demand; notably from Reach 2
 - Increased Brazil production reduces barge demand; mostly from Reach 4, as well as Reach 2.

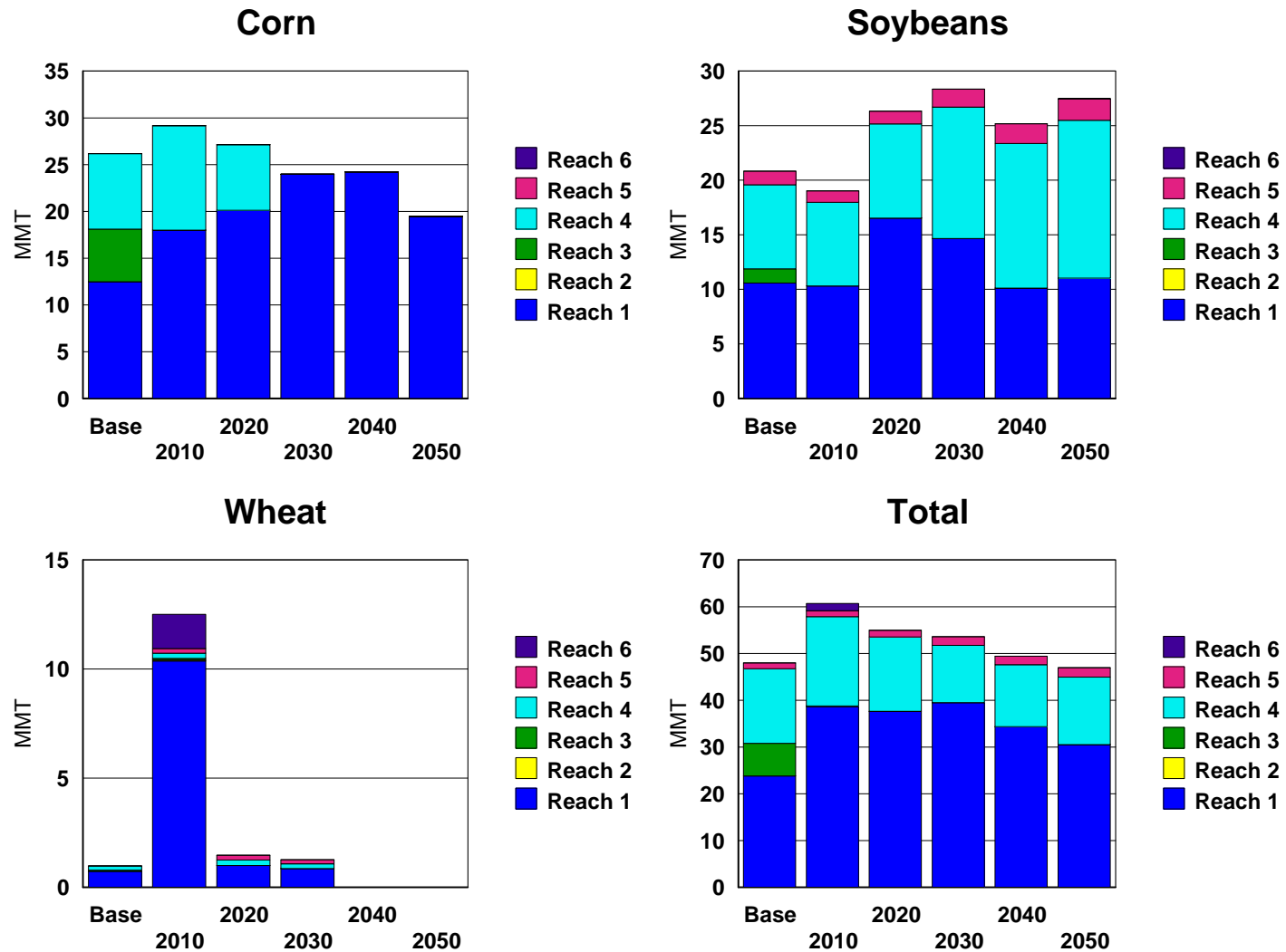
Chance Constrained Risk Model

- Assumes the decision maker is willing to allow constraint violations with some specified probability, α .
 - With multiple constraints, the joint probability of satisfying all constraints simultaneously must be computed.
 - Few distributions allow for analytical computation of the joint cumulative density.
 - There were 30 chance constraints with a probability of satisfying demand.
- Since the forecast variability increases over time,
 - in order to satisfy the chance constraint, over time an increasing amount of US-produced grain is consumed domestically.

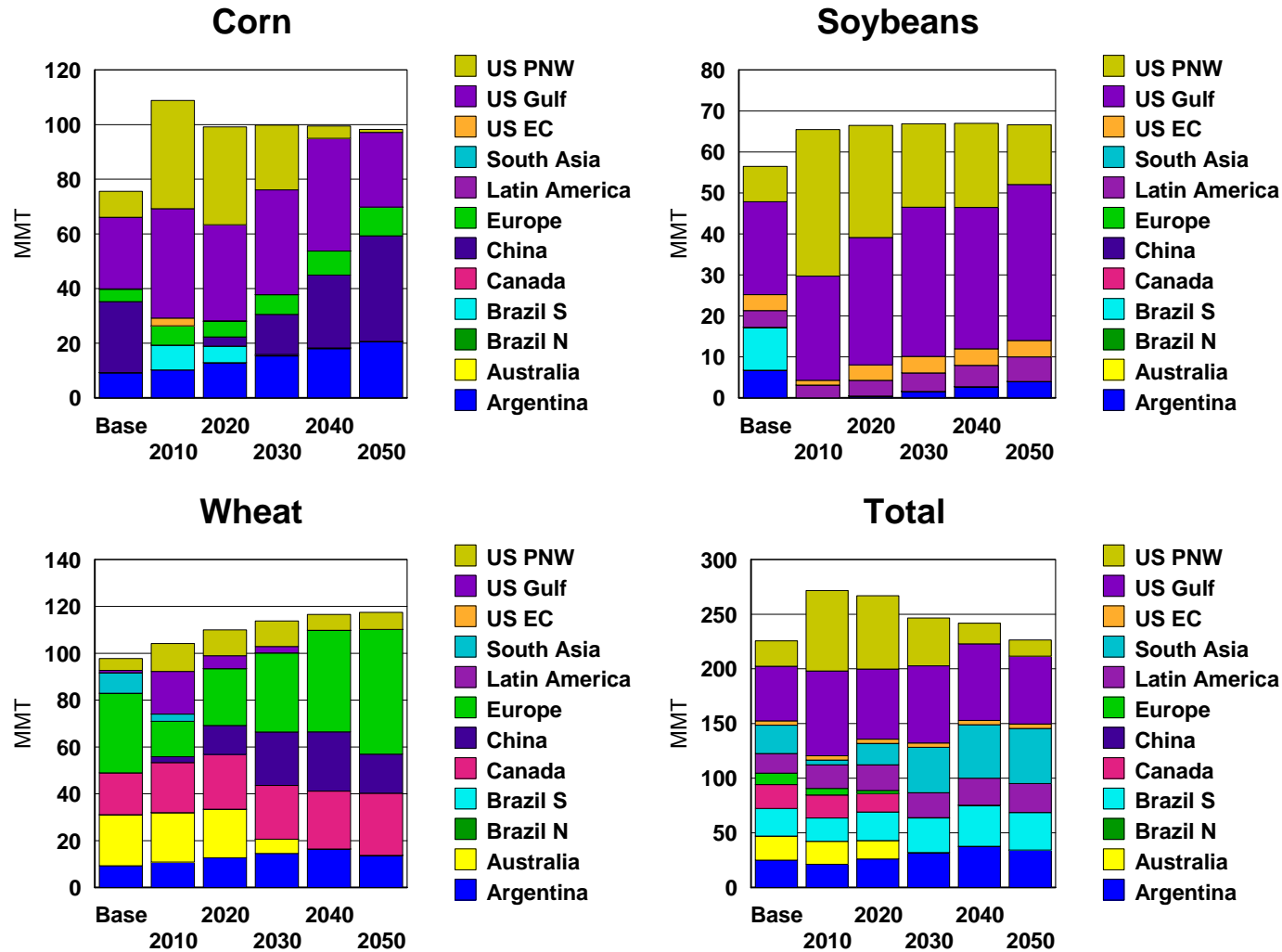
3 Groups of Random Variables

- Consumption
 - for each country/region which are impacted by stochastic nature of consumption function.
- Yield: which impacts production costs.
- Modal rates were specified as a group of econometrically specified functions. Generally, this was a system including:
 - Ocean rates which were related to distance, origin and destination dummies, fuel costs and trend;
 - Barge rates which were related to export levels, shipments on individual reaches, and ocean spreads;
 - Domestic rail rates, estimated separately for each crop, where rail rates were related to distance, distance to barges, trend and the interaction with barge rates from Reach 1.
 - Export rail rates, estimated for each crop, which were related to distance, distance to barge, reach origins and the barge rate at each of the reach origins and the ocean rate spreads.
- Each of these was estimated separately to accommodate the data and other restrictions.
 - estimated from pooled data
 - but the dimensions varied.
 - Joint estimation would require some type of a priori restrictions on the pooling which was thought to be more onerous than the efficiency gains from joint estimation.

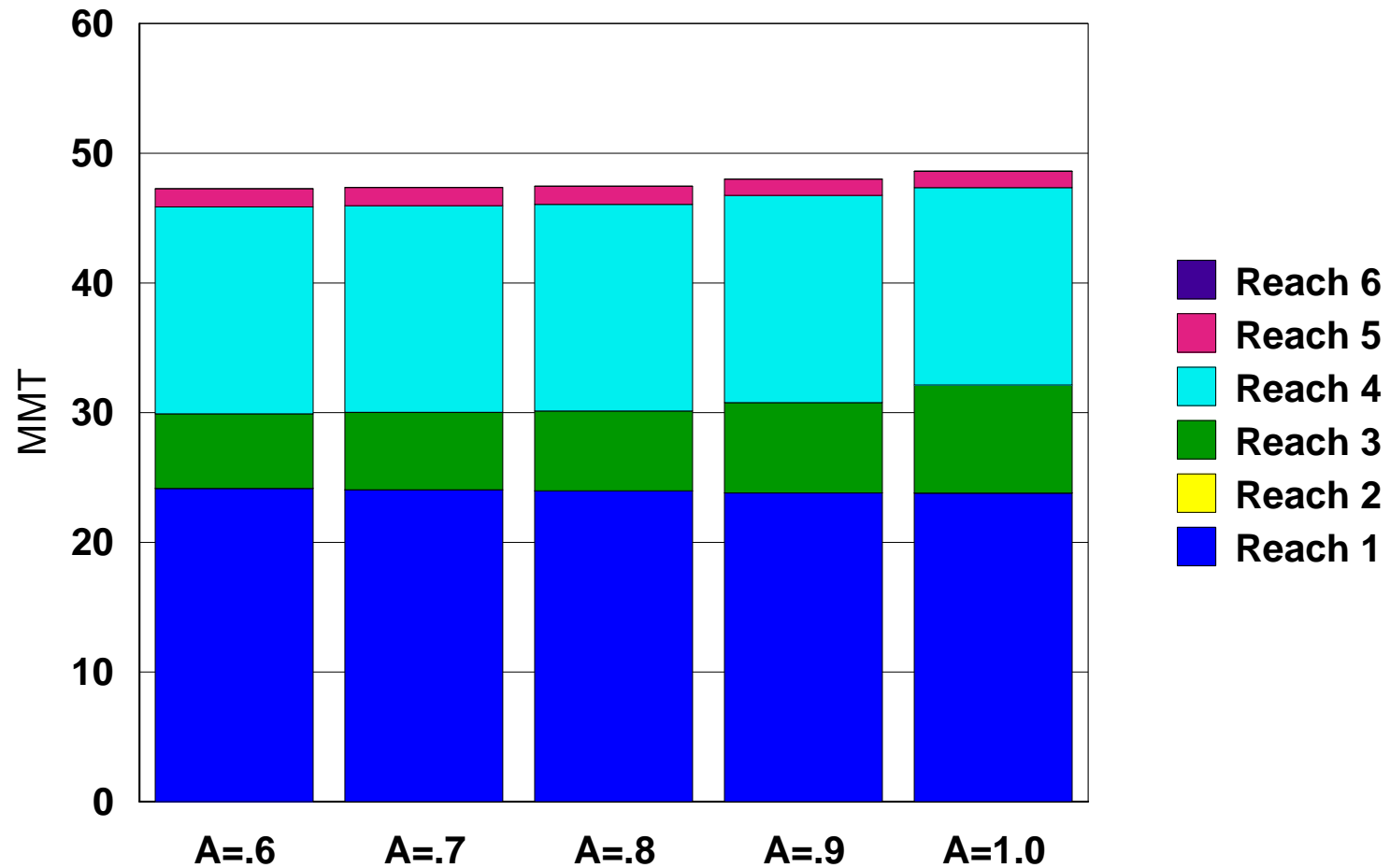
Barge Volume, Current Capacity, Alpha = .9



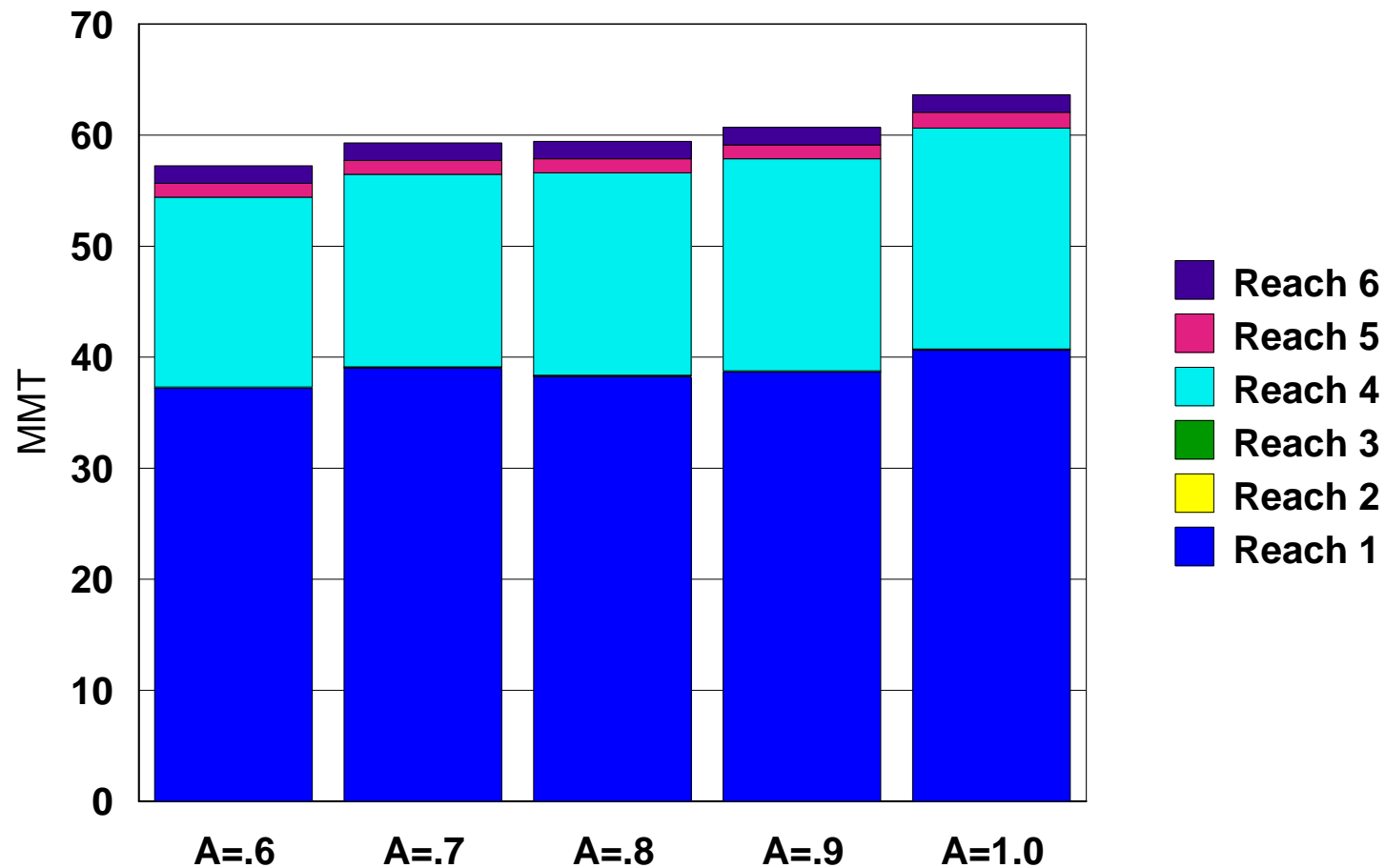
Export Volume, Current Capacity, Alpha = .9



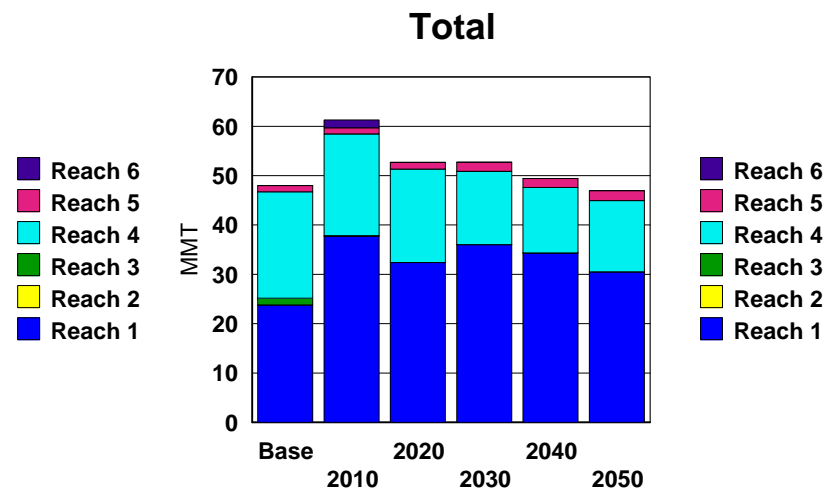
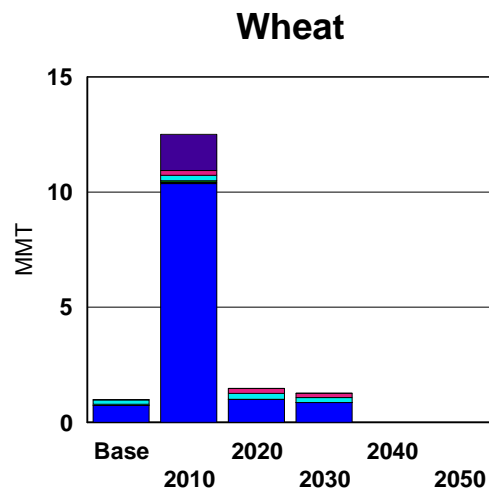
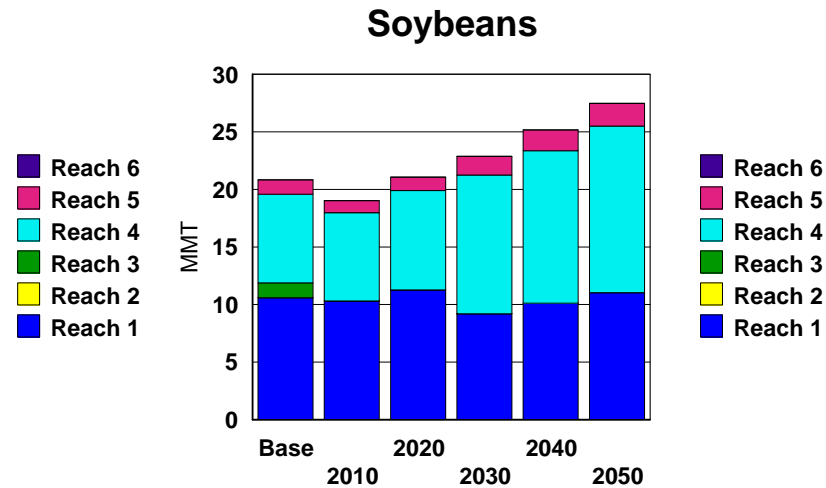
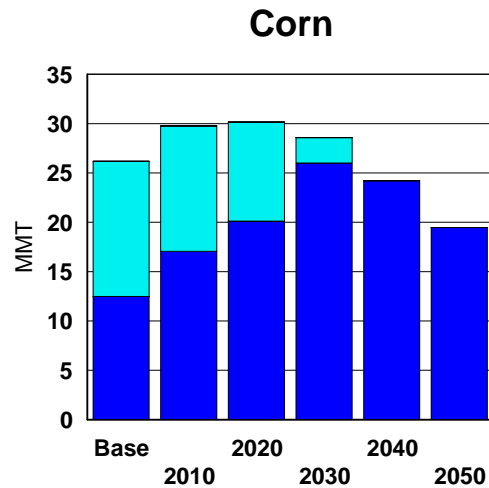
Effect of Alpha on Total Barge Volume for Base Year, Current Capacity



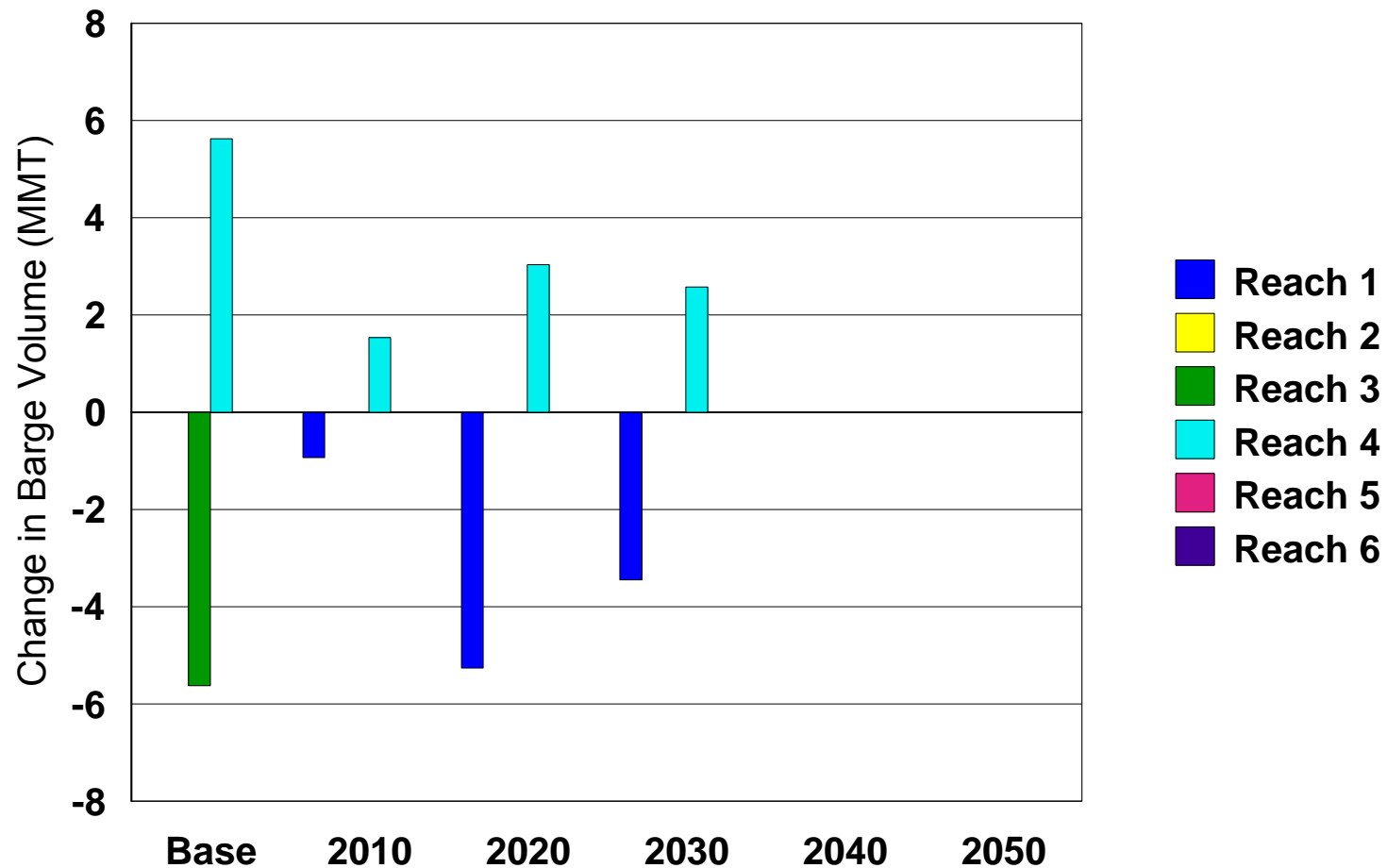
Effect of Alpha on Total Barge Volume for 2010, Current Capacity



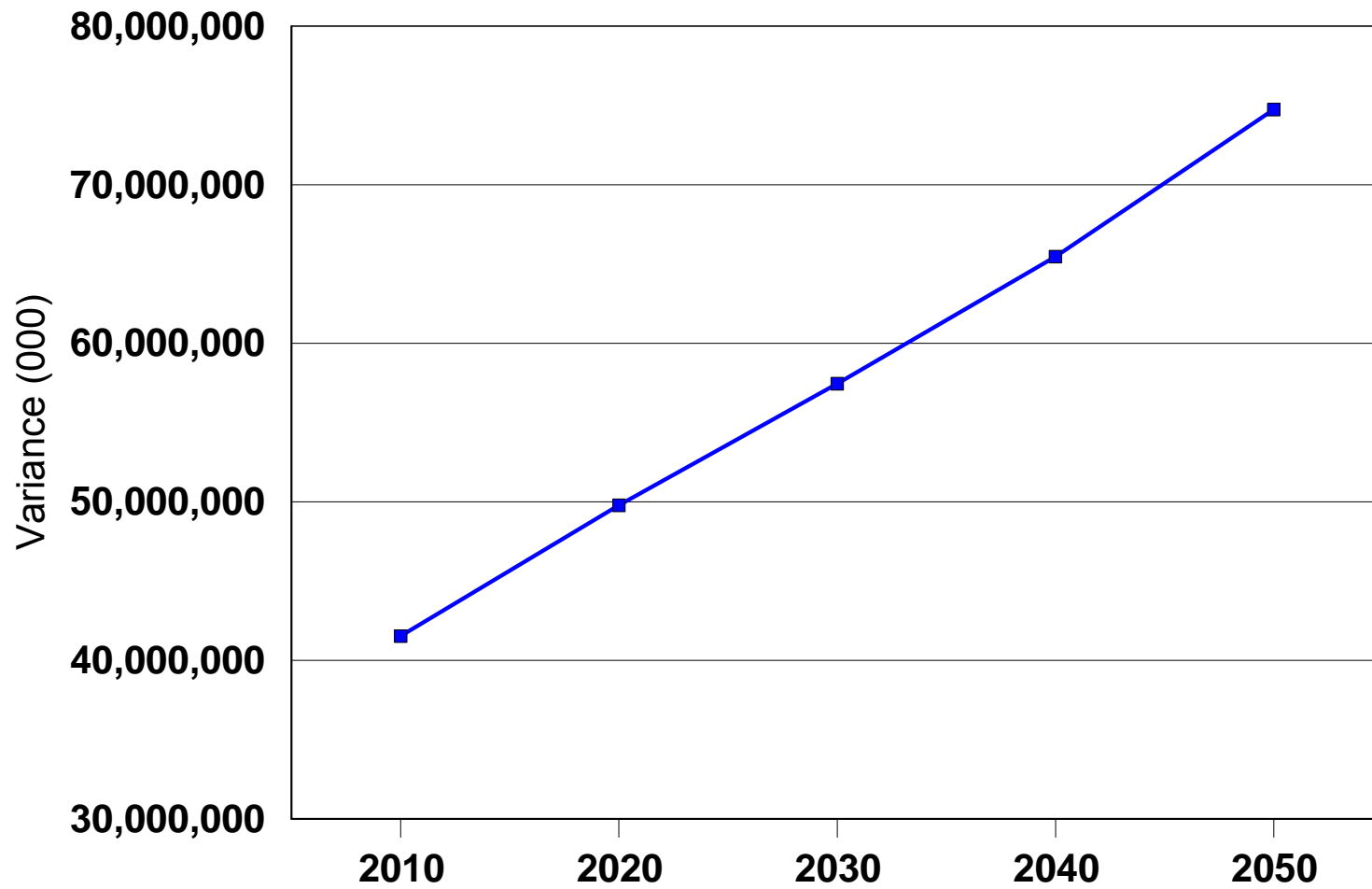
Barge Volume, Expanded Capacity, Alpha=.9



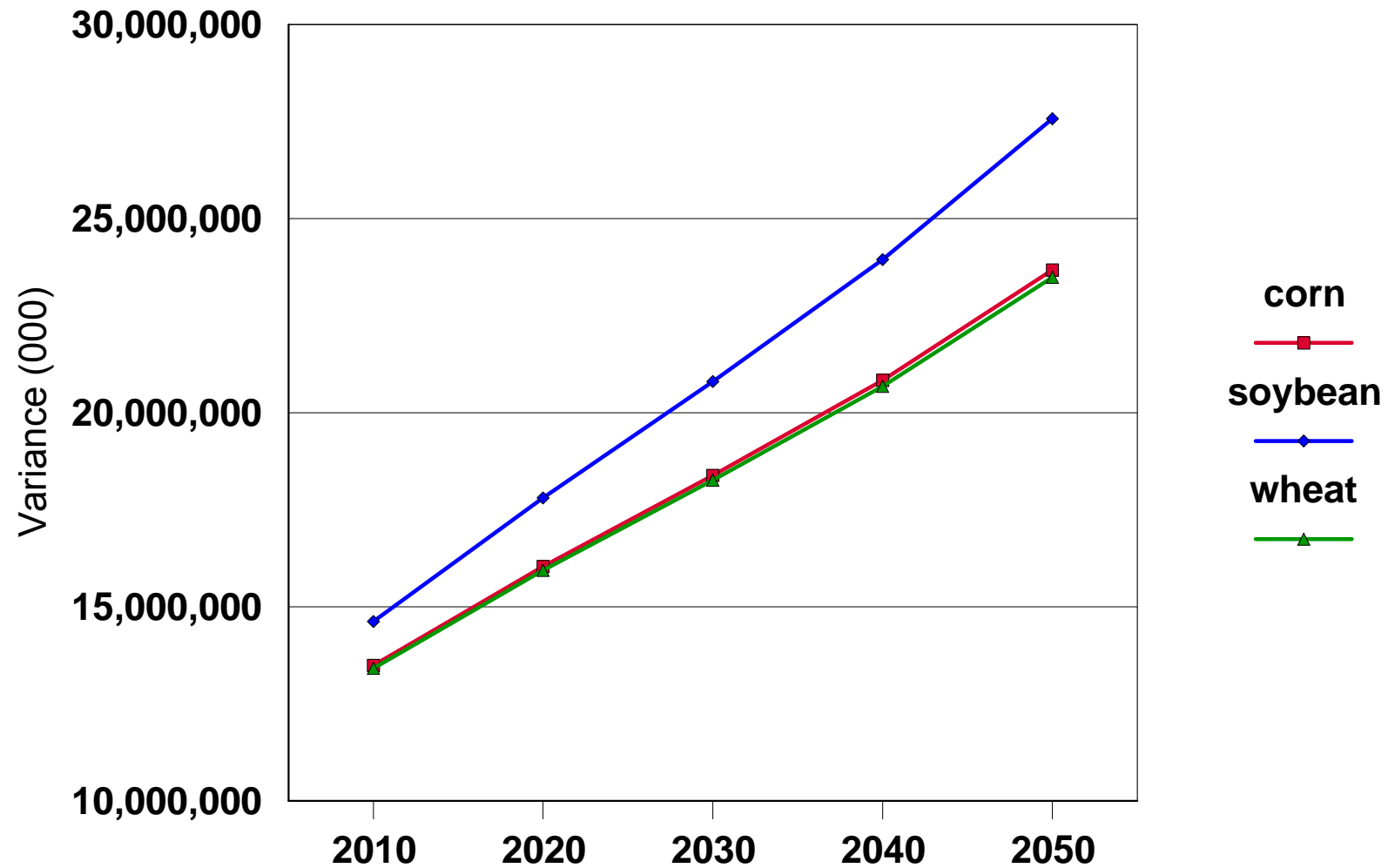
Change in Barge Volume (Expanded – Current) Alpha=.9



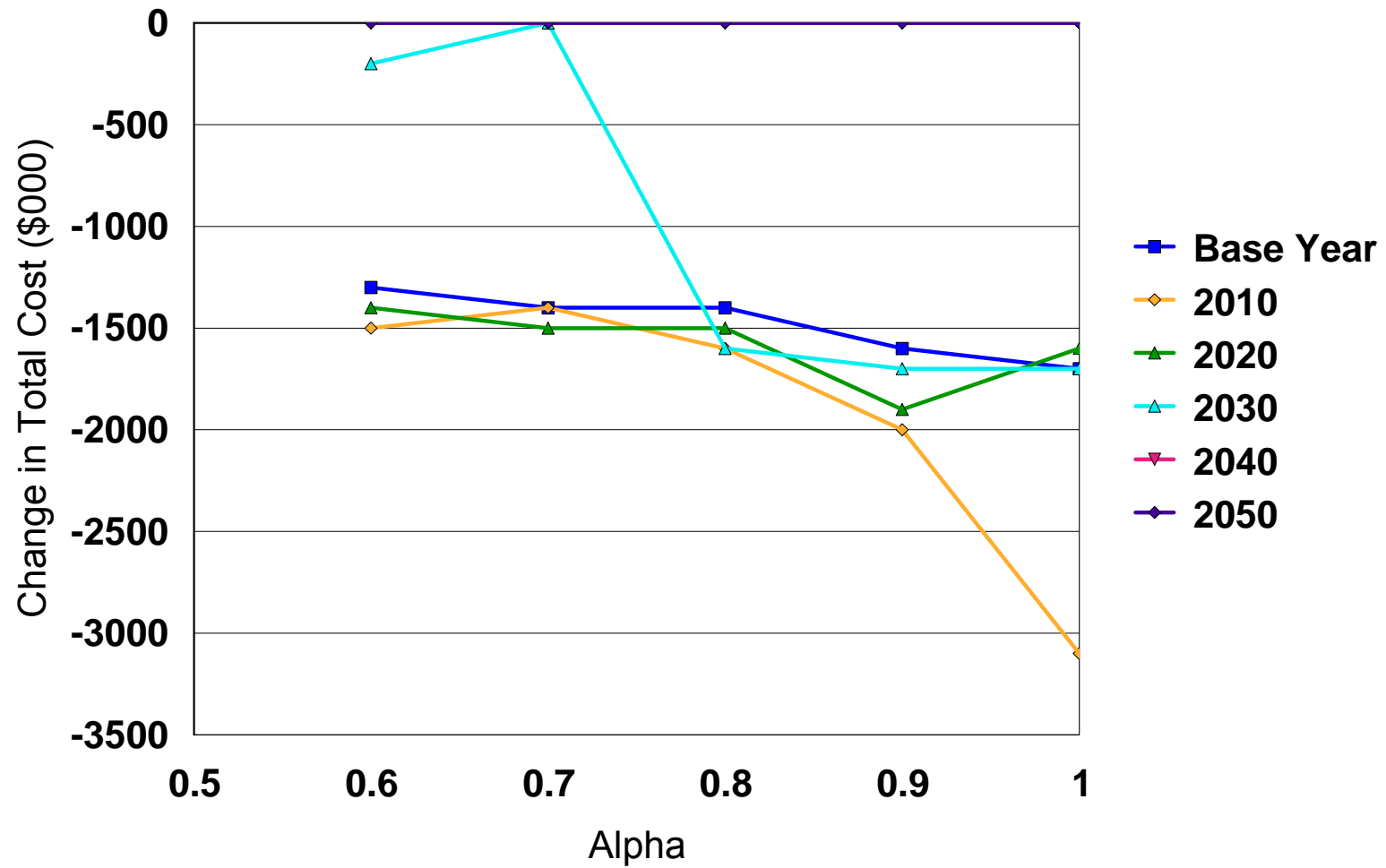
Total Variance



Model Variance over Time



Difference in System Costs: Expanded-Current Capacity



Summary of Results 1

- Major changes impacting barge flows
 - Increased rail competitiveness for selected shipments to:
 - Reach 1 and direct to US Gulf
 - Expansion of domestic use of some grains in selected regions:
 - reducing export demand
 - Higher cost of production in selected crops/regions
 - Brazil N is not low cost vs. US soybean regions
 - Peculiar quality requirements in wheat provide an advantage, despite they are not lowest cost
 - Delay functions become important at Reach 1
 - Farm/trade policies
 - Fastest growth markets for US grains/Oilseeds
 - SE Asia; China (Soybeans); N. Africa.....

Summary of Results 2

- **Projections**
 - Sustained growth is expected
 - Driven by corn, soybeans which are driven by income, population growth and corresponding changes in consumption patterns. This is a key:
 - increased incomes results in shifts to increased corn and soybean demand;
 - US is low cost producer of corn, and soybeans which encourages shifts to those crops, as much as possible
 - Lowest cost regions are tributary to the US Gulf which encourages barge shipments.
 - Though rail is lower cost in some cases, the transfer restrictions would limit movements by that mode.
 - Wheat has nil/negligible growth potential
- Expansion of lock capacity results in increased barge shipment

Summary of Results 2

- Sensitivities: Most critical are
 - Longer-run price elasticity implied at about $-.8$
 - Ocean rate differentials and PNW Exports
 - Increased ocean rate differentials will attract more grains through PNW, and less on barge system; this will occur up to PNW capacity limits
 - Transfer restrictions for rail to barge at St. Louis.
 - If relaxed, there is a sharp change in flows favoring barge origination at StLouis and a net increase in barge flows
 - Free trade in grains would increase barge flows; as would stronger growth in China soybeans and reduced EU production
 - Increased ethanol production and increased Brazil soybean production would take away from barge flows

Other considerations

- St Louis and New Orleans transfer restrictions.
 - The railroads in the United States, as least during our base period, have become very competitive relative to barges in selected movements.
 - This is a significant result as these appear to be targeted origins and for shipments specifically to St. Louis for barge beyond, or, direct to the US Gulf.
 - given these appear to be targeted to the larger volume origin regions has important implications.
 - if the model is run unrestricted, there are large shifts from barges to rail for some of these movements suggesting that in these regions the barges are the residual mode.
- PNW ocean spreads One of the most important impacts affecting barge demand is the spread in ocean shipping costs to Asia from the PNW vs. the US Gulf.
 - During our base period, and much of the 1990s, this value of the 1990s, this value was about \$5/mt.
 - Since then, this spread has increased to as high as \$27/mt, and has since moderated down to the \$16-20/mt range.
 - Greater spreads has a dramatic shift if U.S. grain flows

Concerns

- Impacts of expanded capacity at all reaches impacts “inter-reach” flows
 - Project evaluation should consider impacts of individual reach expansions
- Definition of system Capacity is critical
 - Notably at StLouis and USGulf
- Seasonality: Major concern
 - Annual model and shipment planning
 - Increasingly flows have become much more seasonal due to Brazil/arg
 - Capacity limits to ship all in Dec-February
 - question about providing capacity for seasonal peaks and, what is the definition of seasonal peaks

Reflections/Extensions

- Update and refine modal rates used in the model: rail, barge and ocean
 - Since 2002, rail, barge and ocean shipping rates have experienced some of the most dramatic impacts in recent history.
 - Published shuttle rates may be better
- St. Louis area and US Gulf Restrictions Revisit with scrutiny
- Alternative Stochastic Specifications:
 - Reduce the size/scope somehow to allow use of other more compatible algorithms and solve through simulation
 - Respecify the model to include barge capacity as a constraint, as opposed to a cost (ie delay cost)
- Econometrics of Modal Rate Relationships
 - A critical feature of the stochastic model is the modal rate relationships, which, were used as inputs into the stochastic model
 - Revise and figure a way to estimate simultaneously